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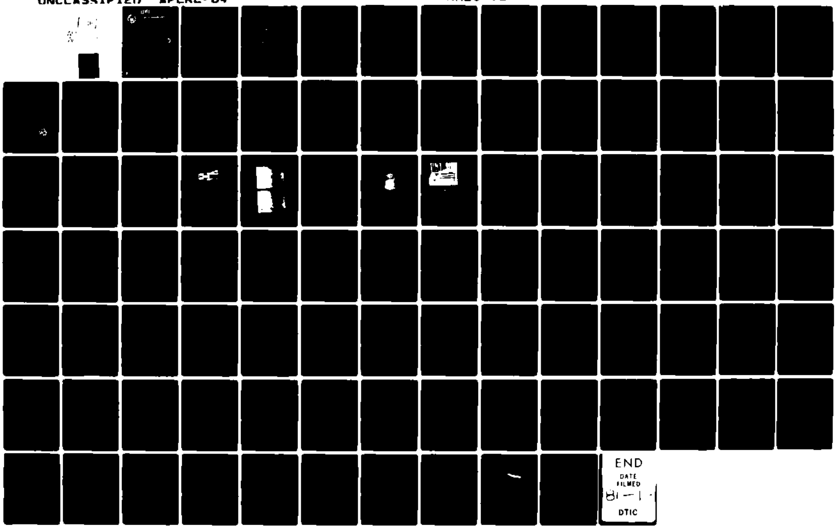

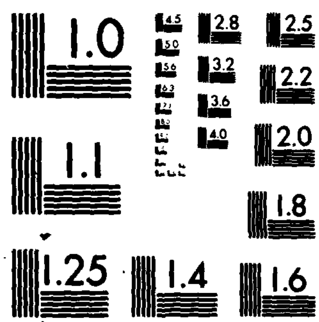
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LAKEHURST, N.J. 08733

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REDUCTION OF EXHAUST SMOKE FROM GAS-TURBINE ENGINES BY USING FUEL EMULSIONS

Propulsion Support Equipment Division
Support Equipment Engineering Department
Naval Air Engineering Center
Lakehurst, New Jersey 08733

21 OCTOBER 1980

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REDUCTION OF EXHAUST SMOKE FROM GAS-TURBINE ENGINES BY USING FUEL EMULSIONS

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Low-internal-phase ratio emulsions of water-in-fuel have been investigated for their potential in reducing exhaust smoke from gas-turbine engines. The unique mechanism is the selective vaporization of the internal phase during the period of droplet heating.

Experiments were conducted in a combustor facility fabricated from T-63 engine hardware using a single-can combustor with a dual-orifice (over)

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20. ABSTRACT

pressure atomizer.

Two series of tests were performed. The initial sequence employed air flow conditions that simulated full engine power (the smokiest condition). During the experiments, the fuel specifications, water concentration, surfactant concentration, and dispersion size were varied, and measurements of exhaust smoke, combustor temperature rise, flame radiation, and combustion efficiency based upon exhaust chemistry were obtained.

The initial series of experiments suggested that a 48 percent reduction in exhaust particulate concentration, based upon a correlation due to Champagne, was possible with an emulsion having a water-to-fuel ratio of 0.1.

The later series of tests was oriented toward optimization of the water concentration for smoke reduction and examination of the complete engine power spectrum. Continuous decreases in exhaust smoke were observed up to the highest concentration tested, a 0.5 water-to-fuel ratio. The maximum reduction in exhaust particulate concentration was 80 percent based upon the Champagne correlation. Emulsions composed of 15 and 30 percent water-in-fuel ratio were tested throughout the engine power range, and smoke reductions were observed at all power points. The greatest reductions were found at the highest power points where the smoke problem is the greatest.

Combustion efficiency was calculated from the exhaust chemistry and decreased with the addition of water. The reduction in efficiency was very small at full power but became quite significant at the lower power conditions. Comprehensive measurements of gaseous exhaust emissions were also reported.

Within the limits of combustor rig testing, the water-in-fuel emulsion concept was shown to have a potential for significant reductions in exhaust smoke at the high power conditions where smoke is the greatest problem; the reductions in combustor performance were minimal at these conditions. The concept shows less potential at the lower power levels of operation. Since increasing the water concentration continued to reduce smoke, in actual engine operation the concentration could be tailored to meet the required smoke level.

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I. INTRODUCTION

Many present-day aircraft turbine engines produce exhaust with visible amounts of smoke. The objectionable conditions occur even though the smoke concentrations are very low and represent very small losses in combustion efficiency. Many recent studies have shown the directions necessary in combuster design for smoke abatement, and excellent results have been obtained. There remains, however, a problem in the testing of existing designs on stationary engine test stands where smoke production levels may be above environmental standards or desires.

Low-internal-phase-ratio emulsions of water-in-fuel have been investigated for their potential in reducing exhaust smoke from gas-turbine engines. The unique mechanism is the selective vaporization of the internal phase during the period of droplet heating; this vaporization and sudden expansion causes the fuel drop to break up into much smaller droplets. The potential for reducing soot formation in heterogeneous combustion is suggested by this increased atomization and dispersion of the fuel.

Experiments were conducted in a combustor facility fabricated from T-63 engine hardware using a single-can combustor with a dual-orifice pressure atomizer. Two series of tests were performed. The initial sequence employed air flow conditions that simulated full engine power (the smokiest condition. The second series employed air flow characteristics at reduced power conditions. During the experiments, the fuel specifications, water concentration, surfactant concentration, and dispersion size were varied. Moreover, measurements of exhaust smoke, combustor temperature rise, flame radiation, and combustion efficiency based upon exhaust chemistry were obtained.

II. SUMMARY

A. During the experiments, it was observed that a concentration of 2% surfactant was sufficient to produce a stable emulsion that allowed significant smoke reduction; no benefit could be ascribed to the use of larger quantities. No effect of dispersion size on smoke reduction was directly observed, although the homogenizing equipment allowed only a small range of dispersion size to be investigated. Fuels which were characterized by high aromatic content and high boiling range were studied; the smoke reduction concept was found to be equally effective in both cases. Specifically, the initial series of experiments suggested that a 48% reduction in exhaust particulate concentration, based upon a correlation due to Champagne, was possible with an emulsion having a water-to-fuel ratio of 0.1. The flame radiation was reduced by 20%, and the reductions in combustor temperature rise and combustion efficiency were minimal. Since there was evidence of a continuing decrease in exhaust smoke with further increases in water concentration, an additional group of experiments was conducted.

B. The later series of tests were oriented toward optimization of the water concentration for smoke reduction and examination of the complete engine power spectrum. Continuous decreases in exhaust smoke were observed up to the highest concentration tested, a 0.5 water-to-fuel ratio. The maximum reduction in exhaust particulate concentration was 80% based upon the Champagne correlation. Emulsions composed of 15% and 30% water-in-fuel ratios were tested throughout the engine power range, and smoke reductions were observed at all power points. The greatest reductions were found at the highest power points where the smoke problem is the greatest.

C. Comprehensive measurements of gaseous exhaust emissions were also obtained. NO_x was reduced by increases in water concentration with the greatest reductions occurring at the higher power levels. CO and unburned hydrocarbons increased with water concentration; the increases were small at full power but became increasingly large at the lower power conditions. Combustion efficiency was calculated from the exhaust chemistry and decreased with the addition of water. The reduction in efficiency was very small at full power but became quite significant at the lower power conditions.

D. Within the limits of combustor rig testing, the water-in-fuel emulsion concept was shown to have a potential for significant reductions in exhaust smoke at the high power conditions where smoke is the greatest problem; the reductions in combustor performance were minimal at these conditions. The concept shows less potential at the lower power levels of operation, but smoke is not usually a problem during low power operation. Since increasing the water concentration continued to reduce smoke, in actual engine operation the concentration could be tailored to meet the required smoke level. Moreover, it is recommended that full-scale engine tests be conducted for the purpose of understanding the effects that water-fuel emulsions have on engine horsepower/operation and exhaust plume visibility.

III. DISCUSSION AND THEORY

A. SMOKE PRODUCTION IN TURBINE ENGINE COMBUSTORS

1. The smoke produced by a gas turbine engine is an aerosol of soot or carbon particles resulting from the incomplete combustion of the fuel. Objectional conditions occur even though the particulate concentrations are very low, typically less than 0.005% by weight, and represent only very small losses in combustion efficiency (1).* The major contribution is formed in the primary zone, but soot may be generated in any part of the combustor where mixing is inadequate and fuel-rich pockets exist. Essentially, the carbon loses to the more active and more available hydrogen in the competition for available oxygen. Most of this fine carbon or soot is consumed in the secondary and quench zones where there is an abundance of air; the remainder becomes exhaust smoke.

*Numbers in parenthesis indicate items within the Bibliography.

2. The physical characteristics of the fuel spray have an important effect on the production of soot. Larger droplets have a longer lifetime, causing higher heat absorption and enhancing soot formation. Reduced spray penetration and cone angle serve to increase the fuel/air ratio in the region of the nozzle leading to an increase in soot production (3).

3. The hydrocarbon structure of the fuel is also known to have a significant effect on the production of soot. The higher molecular weight compounds are more prone to producing soot because of their higher carbon-hydrogen ratio; also they are less volatile and are often pyrolyzed before distilling out of the droplet. The existence of smaller droplets would allow the heavy ends to vaporize sooner so improved atomization may very well reduce this source. The aromatic compounds have a tendency to produce smoke about 30 times greater than that of the paraffins for the same boiling range (7) due to the relatively high stability of the carbon ring (16). This is an important consideration because of the latitude for aromatic composition in JP-5, 0-25% by volume.

B. SMOKE REDUCTION TECHNIQUES

1. Several techniques are generally used to reduce the smoke from new combustor designs: increased mixing and a leaner primary zone to reduce the production of soot and increased residence times in the secondary and quench zones to promote complete burning of the soot (2,3). Considerable success has also been obtained by using the so called "air blast" atomizer, which not only provides a smaller droplet size, but provides a source of oxygen immediately in the region of the nozzle orifice thus reducing the fuel-rich pocket found with pressure atomizers (3).

2. These solutions do not solve the problem associated with the testing of existing designs on stationary engine test stands where smoke production levels may exceed environmental standards. There are several fuel additives available which act to suppress smoke, such as Ethyl Corporation's Combustor Improver #2 and ferrocene. The former is a manganese additive and has potential toxicity problems as well as leading to the accumulation of manganese oxides on critical areas of the turbine; ferrocene also tends to create deposits, but they are sometimes acceptable (4, 5, 6).

C. "MICRO-EXPLOSION" PHENOMENA

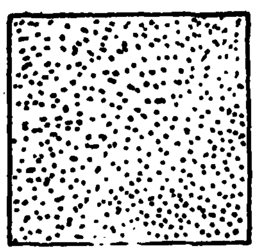
1. The combustion properties of drops of fuel emulsions were first investigated experimentally by Ivanov and Nefedov (14). Burning drops of water-in-oil emulsions and using high-speed cinematography, they showed that the more volatile water vaporized inside the drop as it was heated. The expansion of the water vapor violently tore the drop apart; this "micro-explosion" scattered very small droplets from the parent drop, increasing the total burning rate and reducing the carbon residue. Dryer (22) has

recently reproduced this experiment under a grant from the National Science Foundation.

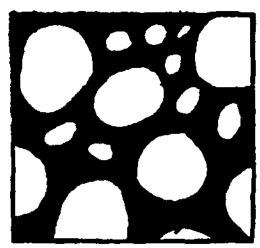
2. The potential for reducing soot formation from gas-turbine engines is suggested by this increase in atomization and dispersion of fuel. Dryer (22) reports several investigations of using fuel emulsions for the reduction of soot from furnaces and boilers; these all involved the use of fuel oils that are heavier than kerosene type jet fuels (JP-5). To the author's knowledge there has been no previous use of emulsions for the reduction of smoke from aircraft turbine engines.

D. CHARACTERISTICS OF EMULSIFIED FUELS

1. The type of emulsion used in this program is known as a low-internal-phase-ratio emulsion of water-in-oil. That is the "dispersed phase", water, is a relatively small fraction of the system and the "continuous phase", fuel, makes up the bulk of the system. The illustration below compares the structure of such an emulsion with its opposite, a high-internal-phase-ratio emulsion. Chemicals known as surfactants are usually required to stabilize emulsions. They are typically a type of molecule which is soluble in water on one end and soluble in oil on the other end. A proper balance of this Hydrophilic-Lipophilic property must be attained to achieve a stable emulsion; an HLB number is assigned to each surfactant to characterize it. The implications of this system are beyond the scope of this work. ICI American has published a description of the system (20). For reference, an HLB of 5.3 was found to be satisfactory. For low-internal-phase-ratio emulsions, the surfactant is usally ionic, so that the apparent charge can help prevent agglomeration and combustion which speeds separation.



Low-internal-phase-ratio water-in-oil



High-internal-phase-ratio oil-in-water

2. Low-internal-phase-ratio emulsions are desirable for the type of work discussed here for two reasons: the change in viscosity is not great and the characteristic size of the dispersed phase (water droplets) is smaller. The reason for the first is obvious; it was found that emulsifying 10% water in the JP-5 raised the viscosity from 1.6 c^S to 2.0 c^S. (High-internal-phase-ratio emulsions usually have very high viscosities and non-Newtonian flow properties.) The second is inherent to the "micro-explosion" phenomena: the size of the dispersed phase must be much smaller than the mean diameter of the fuel spray so that spray drops will contain the emulsion. Emulsions of 10% water in JP-5, stabilized with a surfactant, were examined under a microscope, and the dispersed water droplets were found to be in the range of 1/2 to 2 microns. Since the SMD of the fuel spray was about 85 microns, the spray remains an emulsion. Figure 1 shows two photo micrographs of emulsions created under different conditions. A circle is superimposed to give an indication of the interior of an 85 micron fuel drop. If the dispersion size becomes the same order as a spray drop, the free surfaces of the emulsion will interfere with normal droplet formation process, and quite probably, the drops will not be emulsions, but either pure fuel or water.

IV. EQUIPMENT AND PROCEDURES

A. EXPERIMENTAL EQUIPMENT. With the exception of the fuel emulsification system, all of the experimental equipment used in this program was existing equipment already being used in turbine-fuels research at the U.S. Army Fuels and Lubricants Research Laboratory (AFLRL).

1. FUEL EMULSIFICATION SYSTEM

a. The system used to make the emulsions was a Model 100 Laboratory Homogenizer manufactured by the Gaulin Corporation. It was chosen over other methods, such as ultrasonics, because it provided a capability for varying the dispersion size of the emulsion. Basically, the unit is a high-pressure, positive displacement pump which discharges a crudely mixed medium through a special homogenizing valve (see Figure 1). The mixture is accelerated through the orifice to strike the impact ring at velocities up to 300 m/sec (950 ft/sec); this action shatters the mixture into a dispersion of very small droplets. This dispersion size can be varied by adjusting the orifice size and pressure drop; examples of the resulting emulsions are illustrated in Figure 2.

b. The homogenizer unit was integrated into the fuel system as an in-line emulsification system, thereby reducing the emulsion stability requirements. The system is shown schematically in Figure 3. The fuel and water are crudely mixed in the "mixing tee" upstream of the homogenizer. The first bypass system recycles excess flow because the pump operates at a constant flow rate of 4.1 l/min (65 gph) whereas the combustor only requires 1.9 l/min (30 gph) at the operating conditions used. The second bypass is used to establish the correct flow rates of the two liquids before introducing the fuel into the combustor. The accumulator is necessary to dampen the pulsations in line pressure caused by the piston-compressor action of the homogenizer.

2. EMULSION ANALYSIS. The emulsions were analyzed for dispersion size by using a microscope with 430x magnification. A micrometer slide with 0.1 mm divisions was used to calibrate the scale on the eyepiece. Each division on the eyepiece was equivalent to about .003 mm so droplets of .001 mm could be measured to an accuracy of .0005 mm.

3. COMBUSTOR RIG. The combustor rig used for this study is based on engine hardware from the Allison T-63 engine used in the Navy's TH-57A helicopter. The burner is a single-can type with a dual orifice pressure atomizer centered in the dome as shown in Figure 4. At the exit of the burner can there is a centerbody which diverts the flow into an annulus where the nozzles and turbine blades are normally located. Gas-sampling probes, pressure probes, and thermocouples were arranged circumferentially in one plane of this annulus at various radial positions, as shown in Figure 5. Figure 6 shows the combustor rig as installed and instrumented in the AFLRL combustor lab. Table 1 presents the air flow and fuel flow conditions that were established to correspond with various power points following the guidelines of the manufacturer.

4. FLAME RADIATION MEASUREMENT. Total flame radiation was measured with Model R-2065 Asymptotic Radiometer manufactured by Hy-Cal Engineering. Figure 7 illustrates the installation of this unit. The window is sapphire to permit response to IR radiation out to around 5 microns; this is necessary to see the CO_2 radiation (19). The important feature is that the window is flush with the combustor liner wall and has a 150° viewing angle. Thus, it sees essentially the entire flame zone and measures the total radiation heat load to the wall at that point. This wide viewing angle is important in programs where the temperature patterns may shift due to changes in air-fuel mixing.

5. DATA ACQUISITION SYSTEM. The heart of the data acquisition system is a Hewlett-Packard 9820 programmable calculator; this is coupled to a scanner and digital voltmeter to automatically acquire data and process it. Operating conditions are then printed out for monitoring on a thermal line printer with an update about every ten seconds. The flow rates of the combustor air and fuel were measured with turbine flowmeters. All pressures were sensed with strain gauge pressure transducers activated by regulated power supplies. Chromel-alumel thermocouples, referenced to a $150^{\circ}F$ regulated oven, were used for temperature measurement.

6. EXHAUST ANALYSIS INSTRUMENTATION. Exhaust emissions were measured on-line using the instruments listed on the following page.

Sample	Instrument	Sensitivity
Carbon Monoxide	Beckman Model 315B NDIR	50 ppm to 16%
Carbon Dioxide	Beckman Model 315B NDIR	300 ppm to 16%
Unburned Hydrocarbons	Beckman Model 402 FID Hydrocarbon Analyzer	0.5 ppm to 10% (CH_4)
Nitric Oxide	Thermo-Electron 10A Chemiluminescence Analyzer	3 ppm to 10,000 ppm
Total Oxides of Nitrogen	Thermo-Electron 10A Chemiluminescence Analyzer with NO_x Convertor	3 ppm to 10,000 ppm
Oxygen	Beckman Fieldlab Oxygen Analyzer	0.1 ppm to 100%

The exhaust sample was brought to the instruments through a 350°F heated teflon line and then appropriately distributed.

7. SMOKE ANALYSIS SYSTEM. The system used for measuring exhaust smoke level was designed according to the requirements of SAE-ARP1179. Briefly, a sample of the exhaust is passed through a strip of filter paper. Particulates from the exhaust are trapped on the surface, leaving a spot ranging in "grayness" from white to black, depending on the sample size and particulate content of the exhaust. The spot is then evaluated with a reflectometer. Refer to VB3 for detailed calculation.

8. FUELS. Three fuels of the JP-5 type were used in this program. Two of the three test fuels were specially blended at a local refinery to accentuate the two "smoke sources" within the fuel as previously discussed, i.e., one fuel had a high boiling range and a low aromatic content while the other had a high aromatic content but a lower boiling range. The third test fuel was simply a production-run JP-5 from Ashland Refinery. Table 2 compares the properties of these fuels to the JP-5 specification.

B. PROCEDURES. The objective of this program was to determine the potential of reducing the exhaust smoke from a gas-turbine combustion chamber by emulsifying the fuel with water. The program was separated into seven major phases:

Phase 1 -- Formation and Characterization of Emulsions

Phase 2 -- Combustor Testing to Evaluate Potential for Smoke Reduction

Phase 3 -- Sensitivity of Concept to Pertinent Fuel Properties

Phase 4 -- Support Data on Best Candidate Emulsion

Phase 5 -- Effect of Best Emulsified Fuel on Combustion Throughout the Power Spectrum

Phase 6 -- Evaluation of the Effects of Particulate Emission Rates on Exhaust Plume Visibility

Phase 7 -- Estimate of Effects During Full-Scale Engine Tests

1. In Phase 1, the formation and characterization of stable emulsions of water-in-fuel were investigated. Possible candidate emulsion systems were identified, and an in-line system was developed to create emulsions of variable concentration and quality.

2. During the second phase, these emulsions were tested in a combustor rig operated at the smokiest condition to determine their potential in reducing exhaust smoke and to assess the effects of the fuel-modification on combustor performance, i.e., flame radiation, exhaust emissions, combustion efficiency, and temperature rise. The fuel used in the second phase was a "production run" JP-5.

3. In Phase 3, two specially blended JP-5 fuels were used to determine if the concept was sensitive to boiling-range end-point or aromatic content. These variables constitute two major fuel-related sources of soot formation in combustors.

4. Phase 4 was devoted to further combustor tests using additional water concentrations. Both 100% and 25% power levels were examined in an attempt to identify the emulsion characteristics that were optimum for smoke reduction.

5. During Phase 5, the combustor was operated over the entire power spectrum using the base fuel and fuel emulsions considered appropriate for full-scale engine testing.

6. The effort during Phase 6 was devoted to estimation of probable plume visibility on the basis of measured particulate emission rates.

7. All of the information acquired during the program was utilized during Phase 7. In this activity, estimates were made of the probable effect of fuel-water emulsions on plume visibility and particulate emission rates during full-scale engine tests.

The work associated with Phases 1-3 was performed during 1975, and the results have been reported previously on an interim basis. This report encompasses the entire effort, Phases 1-7, and includes all information previously submitted.

V. ANALYSIS

A. PRESENTATION OF DATA. There are two types of data presentation: the test reports of the individual combustor experiments and the smoke data. Since the smoke data is derived from analysis and curve fitting of smoke spots on filter paper, it is not included in the individual test report which is immediate output from the calculator at the completion of each test.

1. The test reports are presented as Figures 8 through 62 and give summaries of the combustor operating conditions, a survey of the exhaust thermocouple measurements, the exhaust chemistry and the combustion efficiencies. Average values and standard deviations of the air and fuel flow parameters are compared with the desired engine parameters as given in Table 1.

2. The least-squares curve fits of the smoke spot readings for all the experiments are presented in Figures 63 through 77. Many of the experiments are combined on the various figures to help illustrate the effects on smoke reduction.

B. COMBUSTION PARAMETERS

1. Combustion Efficiency. Combustion efficiencies are calculated from the exhaust gas analysis according to a relationship developed by Hardin (11):

$$\eta_b = \left[1 - \frac{A \cdot f(UBH) - 121{,}745 \cdot f(CO - 38{,}880 \cdot f(NO) - 14{,}654 \cdot f(NO_2)}{A \cdot \left[f(CO_2) + f(CO) + f(UBH)\right]}\right] \cdot 100\%$$

where f(i) is the concentration of "i", in the exhaust and A is a constant based on the heat of combustion and hydrogen/carbon ratio of the fuel.

2. Flow Rate. The pressure and flow rate cannot always be attained exactly; in such cases the air flow loading factor is the critical scaling parameter which is matched along with the air/fuel ratio and the inlet temperature. The flow parameter is defined as:

$$FF \equiv \frac{\omega \sqrt{T}}{P}$$

where W = air flow rate
T = temperature
P = air pressure

It is a measure of the mach number of the inlet air flow and hence the residence time in the combustor. This is a standard scaling method used by engine manufacturers (10).

3. <u>Smoke Level</u>. The sample particulate matter, as aforementioned in IVA7, is evaluated using a reflectometer. The calculation which assigns a smoke number (SN) to the sample is as follows:

$$SN = 100 \left(1 - \frac{R_s}{R_w}\right)$$

where R_s and R_w are the diffuse reflectance of the sample spot and the clean filter paper. Exhaust samples are taken over a range of sample sizes around W/A = 0.023 pound of sample per square inch of filter area. The resulting smoke numbers are plotted against log (W/A). These are least-squares fitted with a straight line; the interpolated value of SN at W/A = 0.023 is the reported smoke number for the engine operation condition. Champagne (9) gives a complete description of the procedure and relates the results to particulate concentration and exhaust plume visibility. Troth et al (10) provide a numerical relationship for that correlation:

$$d_s = a_1 \exp (a_2\ SN)\ [1-\exp (-a_3\ SN)] + a_4 \exp [-a_5\ (SN-a_6)^2]$$

where d_s = true smoke density, mg/m^3

SN = EPA Smoke Number

a_1 = 0.8

a_2 = 0.057565

a_3 = 0.1335

a_4 = 0.0942

a_5 = 0.005

a_6 = 27.5

VI. DISCUSSION OF EXPERIMENTAL RESULTS

A. COMBUSTOR OPERATING CONDITIONS

1. Examination of the test reports shows that the air and fuel flow parameters were all quite stable during the tests which normally take about 20 minutes to complete because of the lengthy smoke measurements. (Unfortunately, due to an error in the programming, the "air flow loading factor" was printed out as "0.00" in the first seven experiments. Calculated values are written in.) The differences in fuel flow rate and air/fuel ratio account for the water and surfactant added to the fuel. The actual fuel flow rate was kept the same for all experiments conducted at similar power points. Another deviation in the printed output from the calculator was encountered during the second series of experiments. The method of reporting hydrocarbon emissions was inconsistent with the computer program; corrections have been made on the experiment test reports.

2. Except for the noted variances, a comparison of the operating conditions shows very little variation among the experiments. They are therefore felt to be a valid set of experiments upon which to base conclusions about the use of fuel emulsions to reduce exhaust smoke.

B. CHARACTERIZATION OF EMULSIONS

1. Four emulsion characteristics were found to be important in this program:

a. surfactant type,
b. surfactant concentration,
c. water concentration, and
d. dispersion size.

2. The first has already been discussed briefly. An HLB kit was purchased and used to find the desirable value for a water-in-JP5 emulsion. A surfactant with an HLB of 5.3 (90% SPAN 80*/10% TWEEN 80*) was used for the combustion experiments.

3. The surfactant concentration was also found to have an effect on the stability. ("Stable" here means the emulsion exhibits no separation to the unaided eye; agglomeration and coescence on a microscopic scale always occur to some extent.) The amount of surfactant necessary depended on the concentration of water. Emulsions of 10% water-in-JP5 could be stabilized for up to 12 hours with 2% of the above surfactant, whereas emulsions of 20% and 30% water showed separation in about 15 minutes. Only concentrations of 5% and 10% water were used in the early combustion experiments. Surfactant levels were maintained at the 2% value during the later tests, which included water-to-fuel ratios up to 50%. The in-line homogenizer unit allowed stable emulsions to be maintained during the performance of the tests.

* Trademarks of ICI America, Inc.

4. It should be noted that the percentage definitions are related to the fuel flow above; the total flow of liquid to the combustor was not used as the reference. Thus, the term "20% emulsion" implies a mixture of one part of water to five parts of fuel on a volume basis. Surfactant concentrations are also based upon a measured volume of fuel, and the surfactant was mixed with the fuel prior to initiation of the combustion tests.

5. The dispersion size could be varied by changing the pressure drop across the homogenizer valve as previously discussed. The two photomicrographs of Figure 2 show the dispersions for the pressure drops of 2600 and 200 psi--the two extremes used in the combustion experiments. The scale is 3 microns per division for both pictures. The high-pressure case indicates dispersions of around 1 to 2 microns, whereas the dispersion in the other case is 5 to 10 microns with a few larger sizes apparent.

C. COMBUSTION EXPERIMENTS. In addition to the individual test reports for each experiment, the salient features of the experimental program are summarized in Tables 3 and 4. The following discussion treats several pertinent aspects of the use of emulsified fuels in turbine combustors.

1. Exhaust Smoke

a. Without exception, the addition of water to the fuel in the form of an emulsion resulted in a reduction in exhaust smoke. The results from the early series of experiments, summarized in Figure 78, suggest that significant reduction in smoke can be achieved through the addition of modest quantities of water. Furthermore, the trend of these results implies that larger quantities of water yield further smoke reduction. The more recent experiments confirm this tendency; results are shown for water/fuel ratios up to 50% in Figures 79 and 80. Throughout this series of tests, smoke was further reduced for each increase in water concentration. Although the shape of the curve implies that a limiting value exists, higher concentrations were not attempted since the physical properties of emulsions begin to change at concentrations not too far above this (18).

b. Since the test results indicate that exhaust smoke decreases monotonically as the water concentration increases, there is no clearly defined optimum value for the water content of the emulsion. In practice, the selection of an appropriate blend would be governed by the magnitude of the smoke emission problem and by practical considerations associated with the engine fuel supply system. A body of data was acquired which describes the degree of smoke reduction available over the entire engine operating range. Water-in-fuel ratios of 0.15 and 0.30 were utilized; the results are described in Figures 81 and 82. The full power point corresponds to maximum smoke, and it is particularly significant to note that the greatest smoke reductions were achieved at the high power points. The lower power points are characterized by smaller smoke reductions, but the smoke levels are also low under low power conditions. In terms of smoke number, at the full power point, reduction by a factor of approximately 2 is possible at the 0.15 water-in-fuel ratio, while the addition of 0.30 water-in-fuel ratio allows smoke reduction by a factor of about 3.

c. During the early series of experiments, an attempt was made to produce emulsions having different dispersion sizes by varying the homogenizer pressure drop. Estimated dispersion sizes ranged from 1 to 10 microns; these values are much smaller than the SMD of the spray. When these mixtures were tested, no effect of dispersion size was observed. However, it is probable that the relatively unstable emulsions produced with low surfactant concentrations are characterized by larger dispersion sizes. The results shown in Figure 78 indicate that the smoke reduction is affected by surfactant concentrations below a level of about 2%. Thus, it may be inferred that there is some effect of dispersion size, but the effect is quite small if the surfactant concentration and initial dispersion are sufficient to create a stable emulsion.

2. Combustor Temperature Rise. There is no apparent effect on temperature rise; this could be expected considering the very small amount of water actually added. With an overall fuel/air ratio of 0.0198, an addition of 12.1% wt (10% vol) of water based on the fuel is only an addition of 0.24% wt of the total flow. Assuming the specific heat of water vapor is twice that of air, the resultant decrease in temperature rise should be about 0.5%. If the temperature rise is typically about 630°C (1170°F), the effect is only 3°C (6°F)!

3. Combustion Efficiency. Combustion efficiencies were calculated from the combustor exhaust chemistry, and the results are shown in Figures 83 and 84. At full power, the efficiency is reduced by less than 1% at water/fuel ratios of 0.50. However, the effect of water addition is more noticeable for part load operation. As shown in Figure 84, the combustion efficiency for a 0.30 water-in-fuel emulsion at the 10% power point is about 4% lower than the value associated with the base fuel.

4. Flame Radiation. Burning emulsions of 10% water consistently resulted in about a 20% reduction in flame radiation. This is consistent with the idea that less soot is being produced in the primary zone.

5. Exhaust Chemistry. Measurements of exhaust concentrations were obtained for unburned hydrocarbons, carbon monoxide, and oxides of nitrogen. The results are summarized, with respect to water fuel ratio and power point, in Figures 85 through 90. In general, it may be observed that an increase in the water concentration corresponds to an increase in emission of unburned hydrocarbon and carbon monoxide and a decrease in emission of oxides of nitrogen. The changes are significant; the emission of oxides of nitrogen can be halved by the addition of 40% water, but the cost of this reduction is an increase of the same magnitude in emission of hydrocarbons. The observed trend corresponds to the effect of a cooler flame zone. The cooler flame may be due either to a water quench effect or to changes in the mixing of air and fuel. The increase dispersion of the fuel as a result of micro-explosions would reduce the level of high temperature diffusion-zone combustion and promote cooler premixed combustion.

D. <u>SENSITIVITY TO FUEL PROPERTIES</u>. The reductions in smoke brought about by emulsifying the fuel were equally effective with high aromatic fuels and fuels with high end points as evidenced by experiments 16 through 19. Therefore, no problems are foreseen in the application of this concept due to variations in fuel properties.

VII. EVALUATION OF CONCEPT AND APPLICATION OF RESULTS

Two correlations, attributed to Champagne (9) and Kelly (21), have been located to establish the correspondence between smoke number and plume visibility. Champagne provides an indication of the size of a visible plume in terms of smoke number (or smoke concentration). The correlation due to Kelly is a summary of data obtained from Navy jet engine test facilities. Both of the correlations are presented in Figure 91. Obviously, reductions in smoke number coincide with reductions in plume visibility, but the actual relationship depends upon the engine and installation. This program has shown that fuel emulsions can be used to reduce exhaust smoke with negligible effects on combustor performance. Therefore, it is concluded that there would be reductions in plume visibility if such a fuel is used in a full-scale engine, but the extent of the reduction cannot be predicted.

The concept of water-in-fuel emulsions reducing exhaust smoke from gas turbine engines appears to have its greatest application at full power conditions where the smoke problem is most severe. The greatest reductions in smoke were obtained under full power conditions, and the effect of water addition on combustion efficiency and combustor temperature rise was smallest at these points. Because the smoke levels were found to be monotonically decreasing with increased water concentration, it appears that the addition of water can be tailored to meet the level of smoke being produced.

The adaption of the technique to full-scale engine testing could be accomplished in two ways: if the fuel control system is flexible enough to accommodate the required increase in fuel flow, the easiest method would be to emulsify the fuel upstream of the high-pressure pump; the other possibility is to emulsify the fuel between the fuel control and the nozzle ring by temporarily replacing a section of the high-pressure line with an emulsification system similar to the one used in this program. The choice may depend on the individual engine.

VIII. RECOMMENDATION

Two important performance items cannot be quantified on a combustor test facility; these factors are (1) the effects on engine horsepower and operation, and (2) the effects on exhaust plume visibility. It is therefore recommended that full-scale engine tests be conducted in order to define these features of water-fuel emulsion time.

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TABLE 1 - T-63 COMBUSTOR RIG OPERATING CONDITIONS

Mode	% Power	BIP kpa (psia)	BIT °C (°F)	ω_a kg/s (lb/s)	ω_f kg/m (lb/m)	F/A	FF	BOT °C (°F)
Ground Idle	10	252 (36.6)	149 (300)	0.699 (1.54)	0.46 (1.01)	.0109	1.158	561 (1042)
--	25	311 (45.1)	178 (353)	0.0821 (1.81)	0.59 (1.31)	.0121	1.145	648 (1199)
Descent	40	363 (52.6)	204 (400)	0.948 (2.09)	1.74 (1.64)	.0131	1.163	699 (1290)
Cruise	55	417 (60.5)	221 (430)	1.03 (2.27)	0.89 (1.97)	.0145	1.147	759 (1399)
Climb/Hover	75	461 (66.9)	244 (472)	1.12 (2.46)	1.11 (2.45)	.0166	1.123	848 (1559)
Takeoff	100	525 (76.2)	273 (524)	1.21 (2.66)	1.43 (3.16)	.0198	1.094	971 (1780)

Nomenclature

BIP: Burner inlet air pressure
BIT: Burner inlet air temperature
ω_a : Air flow rate
ω_f : Fuel flow rate
F/A: Fuel/air ratio
FF : $\omega_a \sqrt{BIT}/BIP$
BOT: Typical burner outlet temperature

TABLE 2 - FUEL PROPERTIES

	FUEL*			
	JP5-HBR	JP5-HA	JP5-P	JP5-Spec.
Composition				
Saturate, normal	18.8	15.8	5.8	--
Saturate, iso- and cyclo-	67.8	59.9	80.9	--
Aromatic	13.4	24.3	13.3	<25%
Volatility				
Distillation				
Initial (°F)	390	366	356	--
10%	406	380	384	400 max
20%	412	384	394	--
50%	430	394	422	--
90%	488	436	476	--
95%	510	466	490	--
Final	536	496	504	550 max
Flash Point, °F	162	145	142	140 min
Gravity, API (60°F)	42.7	42.1	42.4	36 to 48
Specific Gravity (75°F)	.81	.81	.81	.788 to .845
Fluidity				
Freeze Point, °F	-22	-52.6	-54	-51 max
Viscosity (100°F)	1.78	1.37	1.59	--
Combustion				
Aniline Gravity Product	6700	5759	6285	4500 min
Heat of Combustion, BTU/lb	19,827	19,702	19,757	18,300 min

*JP5-HA was the high aromatic JP5,
JP5-HBR was the high boiling range JP5, and
JP5-P was the production JP5.

TABLE 3 - SUMMARY OF COMBUSTOR EXPERIMENTS
PROGRAM PHASES 1-3
All Runs at Full Power Conditions

Exper. No.	Date	Base Fuel[1]	Water Conc. ~Vol%	Surfactant Conc. ~Vol%	ΔP[3] ~psi	NO ~ppm	NO_x ~ppm	THC ~ppm	CO ~%	Smoke No.	Particulate[2] Conc. ~mg/m^3	Combustion Efficiency ~%	Combustor Temp. Rise ~°C (°F)	Combustor Flame Radiation ~kw/m^2
1	6/13/75	JP5-P	0	0	--	57.5	61.5	2.9	0.033	24.4	3.22	99.6195	661 (1221)	--
2	6/13/75	JP5-P	10	2	2600	49.0	53.0	7.4	0.036	16.9	1.95	99.5618	638 (1181)	--
3	6/13/75	JP5-P	10	2	1600	45.0	55.5	6.8	0.040	17.0	1.96	99.5254	637 (1179)	--
4	6/13/75	JP5-P	10	2	200	43.5	54.5	6.0	0.040	17.3	2.01	99.5311	632 (1170)	--
5	6/18/75	JP5-P	0	0	--	52.5	58.0	3.6	0.032	25.5	3.45	99.6121	623 (1153)	19.9
6	6/18/75	JP5-P	10	1	2600	44.5	51.5	5.3	0.038	18.5	2.19	99.5484	637 (1178)	15.9
7	6/18/75	JP5-P	10	1/2	2600	48.0	56.2	4.8	0.033	21.5	2.68	99.6096	645 (1193)	16.7
8	6/19/75	JP5-P	0	0	--	52.6	58.5	3.4	0.033	27.1	3.80	99.6000	618 (1144)	--
9	6/23/75	JP5-P	0	0	--	58.0	63.5	2.2	0.032	27.6	3.91	99.6344	647 (1197)	19.1
10	6/23/75	JP5-P	0	2	--	51.5	58.3	3.8	0.035	26.6	3.69	99.5690	635 (1175)	19.1
11	6/25/75	JP5-P	0	0	--	55.4	61.5	3.4	0.032	27.2	3.82	99.6142	634 (1174)	18.6
12	6/25/75	JP5-P	10	3	2600	45.0	52.5	5.7	0.040	18.9	2.25	99.5225	633 (1172)	14.2
13	6/25/75	JP5-P	5	2	2600	51.7	59.5	3.4	0.033	21.4	2.66	99.6193	646 (1195)	15.4
14	6/25/75	JP5-P	5	1	2600	50.5	5715	3.6	0.035	23.0	2.95	99.5872	633 (1171)	14.7
15	6/25/75	JP5-P	5	1/2	2600	52.5	58.5	3.6	0.035	24.0	3.14	99.5838	628 (1163)	14.5
16	6/27/75	JP5-HA	0	0	--	60.5	66.5	2.5	0.033	33.6	5.55	99.6089	635 (1175)	17.9
17	6/27/75	JP5-HA	10	2	2600	48.5	54.5	5.3	0.039	23.8	3.11	99.5286	623 (1170)	14.1
18	6/27/75	JP5-HBR	0	0	--	52.5	60.0	3.2	0.036	25.0	3.35	99.5741	621 (1150)	14.6
19	6/27/75	JP5-HBR	10	2	2600	45.0	51.6	6.4	0.041	15.4	1.74	99.5011	622 (1152)	11.9

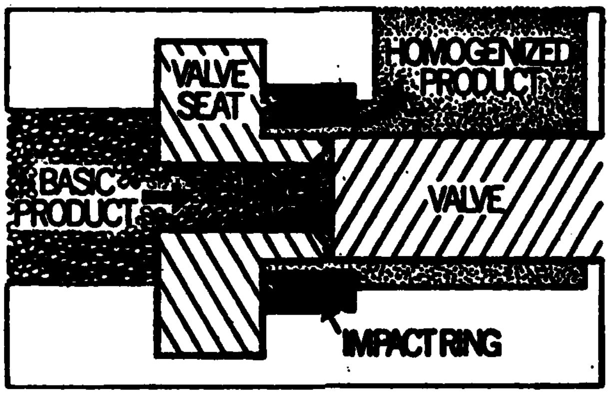
1. JP5-P was the production JP5,
   JP5-HA was the high aromatic JP5, and
   JP5-HBR was the high boiling range JP5.

2. Calculated from Champagne's correlation to Smoke Number (Ref. 9).

3. Pressure drop across "Homogenizer valve" which affects dispersion size.

TABLE 4 - SUMMARY OF COMBUSTOR EXPERIMENTS
PROGRAM PHASES 4-7
Fuel For All Runs Includes Surfactant 2% By Volume
Homogenizer Valve Pressure Drop = 2600 PSI For All Emulsions

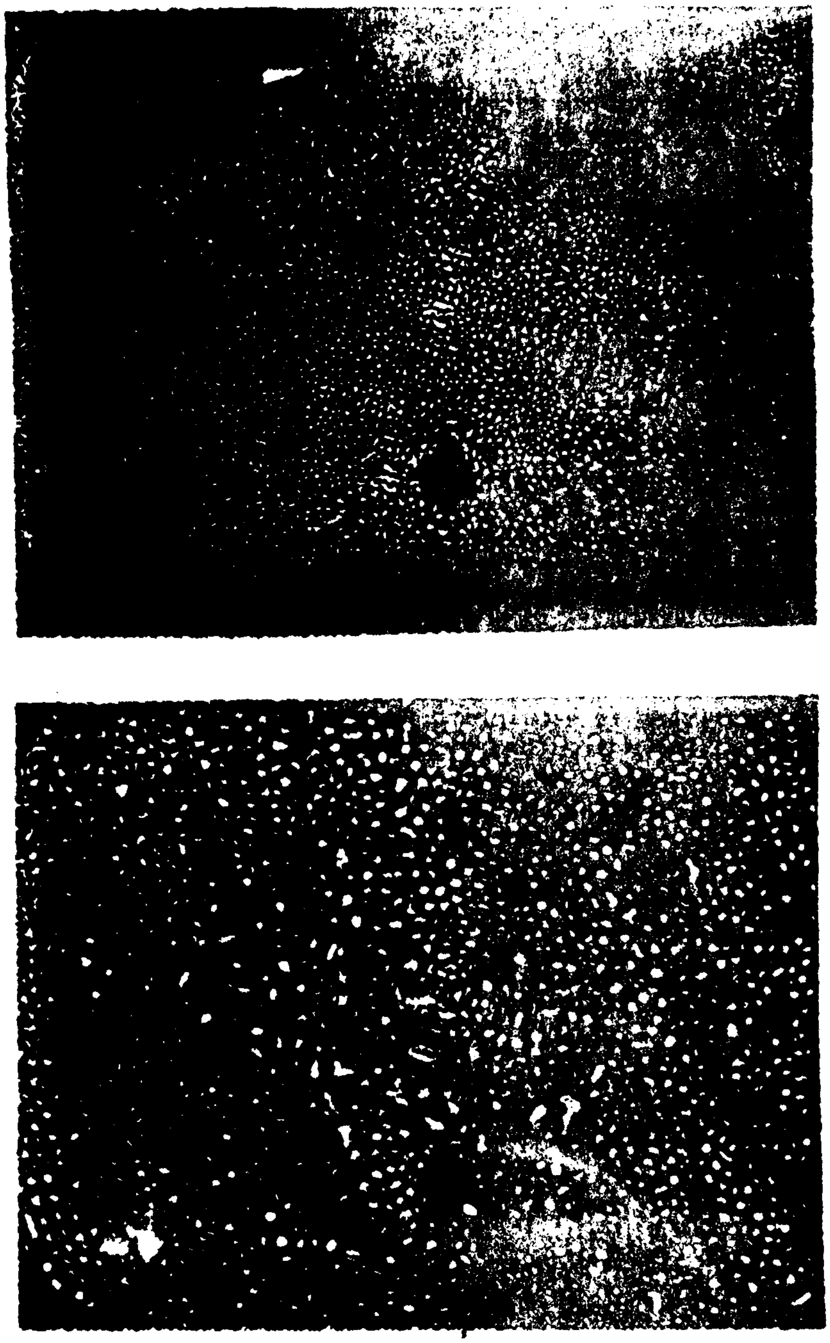
Exper. No.	Date	Base Fuel	Water Conc. Vol %	Power Point %	NO PPM	NO_x PPM	THC PPM (Propane)	CO %	Smoke No.	Particulate Conc. mg/m^3	Combustion Efficiency %	Combustor Temp Rise °C (°F)
20	6/17/76	JP5-P	0	100	55.5	62.0	9.4	.036	29.7	4.43	99.5442	----------
21	6/17/76	JP5-P	5	100	46.5	55.5	6.1	.043	19.0	2.26	99.4818	643 (1189)
22	6/17/76	JP5-P	10	100	43.5	51.5	8.3	.045	21.5	2.68	99.4568	648 (1199)
23	6/17/76	JP5-P	15	100	44.0	52.3	5.4	.044	17.6	2.05	99.4976	657 (1215)
24	6/17/76	JP5-P	20	100	33.0	41.5	11.4	.052	14.7	1.64	99.3529	642 (1188)
25	6/17/76	JP5-P	25	100	29.5	38.3	14.7	.058	12.2	1.33	99.2685	637 (1178)
26	6/18/76	JP5-P	0	100	50.3	60.5	3.6	.039	29.4	4.35	99.5348	642 (1188)
27	6/18/76	JP5-P	5	100	46.3	55.0	6.3	.046	22.3	2.82	99.4528	648 (1198)
28	6/18/76	JP5-P	30	100	26.3	34.4	20.8	.063	12.9	1.41	99.1670	639 (1183)
29	6/18/76	JP5-P	40	100	20.5	29.5	30.7	.073	10.2	1.09	99.0028	625 (1156)
30	6/18/76	JP5-P	0	25	11.7	19.3	140.0	.096	14.6	1.63	96.7323	416 (781)
31	6/18/76	JP5-P	10	25	12.3	17.0	253.3	.122	8.6	0.91	95.0419	413 (776)
32	6/18/76	JP5-P	20	25	10.7	13.7	327.7	.135	5.6	0.59	94.0669	406 (762)
33	6/18/76	JP5-P	30	25	8.8	11.3	393.7	.142	4.8	0.51	93.0364	386 (727)
34	6/18/76	JP5-P	40	25	8.0	9.7	468.0	.152	3.3	0.35	92.1171	392 (738)
35	6/21/76	JP5-P	0	100	56.0	61.7	3.6	.036	28.5	4.13	99.5685	646 (1194)
36	6/21/76	JP5-P	40	100	25.0	31.0	25.5	.070	9.3	0.99	99.0824	622 (1152)
37	6/21/76	JP5-P	50	100	20.5	26.4	38.9	.080	8.2	0.87	98.8921	617 (1142)
38	6/21/76	JP5-HBR	0	100	49.8	55.5	4.3	.040	26.6	3.687	99.5018	624 (1155)
39	6/21/76	JP5-HBR	15	100	35.8	41.5	14.2	.056	13.2	1.451	99.2684	626 (1158)
40	6/21/76	JP5-HBR	30	100	26.0	33.0	28.6	.069	9.3	0.990	99.0190	606 (1123)
41	6/21/76	JP5-HBR	0	75	29.4	39.0	34.7	.067	24.3	3.203	98.8143	543 (1009)
42	6/21/76	JP5-HBR	15	75	23.0	29.3	89.0	.099	12.3	1.339	97.9108	514 (958)
43	6/22/76	JP5-HBR	30	75	20.5	25.0	101.3	.104	7.6	0.803	97.8667	534 (994)
44	6/22/76	JP5-HBR	0	55	22.5	30.3	75.7	.084	19.0	2.265	98.0293	453 (848)
45	6/22/76	JP5-HBR	15	55	18.5	23.8	158.0	.109	9.9	1.057	96.8638	430 (805)
46	6/22/76	JP5-HBR	30	55	15.3	18.8	194.3	.121	5.9	0.622	96.4240	437 (818)
47	6/28/76	JP5-HBR	0	40	15.4	21.2	112.3	.091	13.3	1.463	97.3384	449 (840)
48	6/28/76	JP5-HBR	15	40	12.8	16.8	200.0	.120	5.2	0.548	96.0315	440 (824)
49	6/28/76	JP5-HBR	30	40	10.2	12.7	270.3	.136	3.3	0.350	95.0206	442 (792)
50	6/28/76	JP5-HBR	0	25	11.0	15.3	163.7	.114	7.3	0.771	96.1639	414 (778)
51	6/28/76	JP5-HBR	15	25	9.3	12.3	286.7	.135	3.4	0.360	94.4994	404 (759)
52	6/28/76	JP5-HBR	30	25	7.5	9.5	374.7	.148	2.2	0.235	93.0219	385 (725)
53	6/28/76	JP5-HBR	0	10	6.8	9.5	249.7	.124	6.8	0.717	94.0701	347 (657)
54	6/28/76	JP5-HBR	15	10	5.3	8.2	437.7	.150	2.9	0.308	91.1468	349 (660)
55	6/28/76	JP5-HBR	30	10	4.4	6.6	511.3	.160	1.8	0.193	89.8932	327 (620)



Close-up of a Gaulin homogenizing valve section. Product enters the valve area at high pressure. The pressure forces open the pre-loaded adjustable valve and the product passes through the aperture where an instantaneous pressure drop to less than an atmosphere occurs, causing shearing action and cavitation bubbles. The product then strikes the impact ring at a velocity of about 57,000 ft/min, further shattering the particles by impact and implosion of the bubbles. The homogenized product is discharged at a pressure sufficient for movement to the next processing stage.

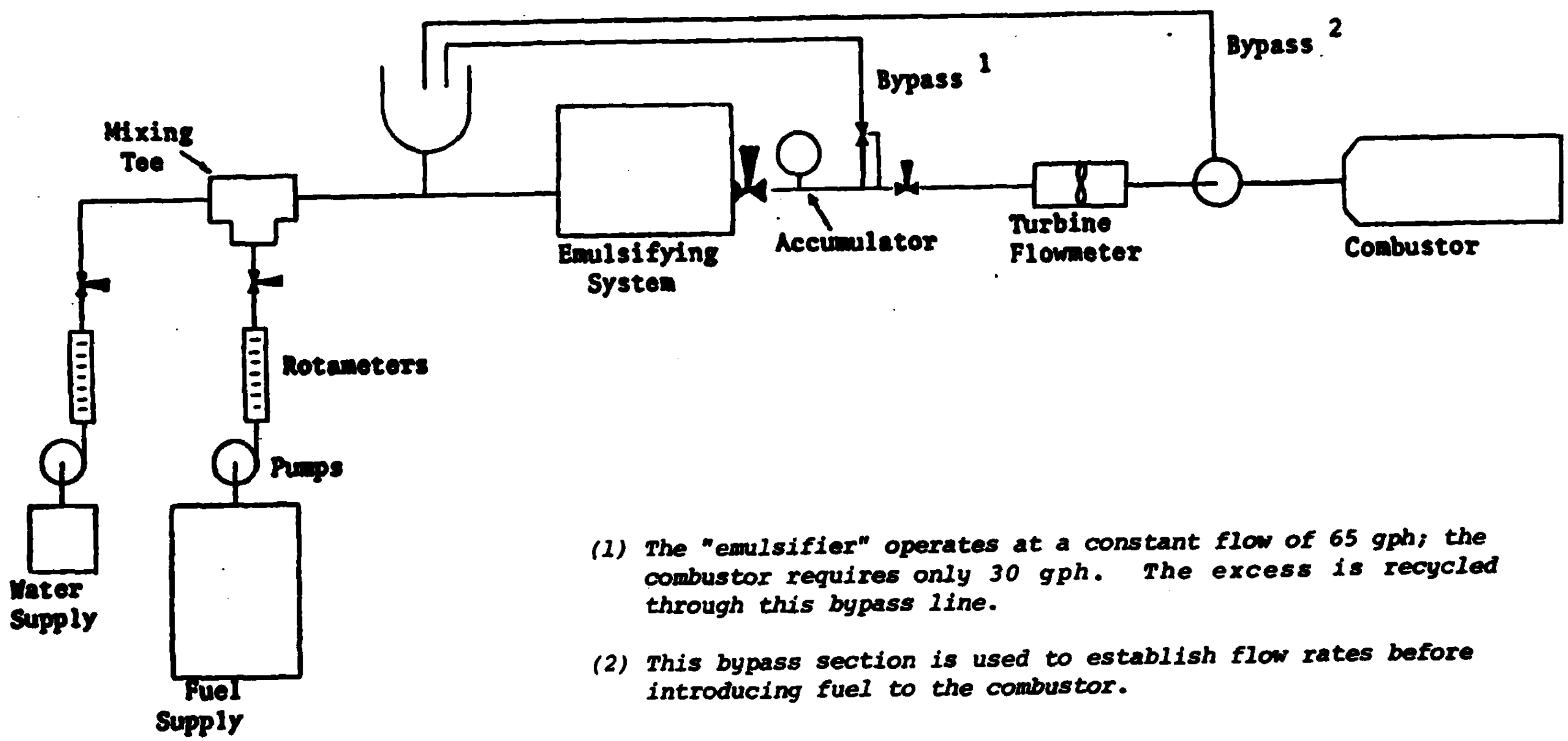
(from Bibliog 4)

Figure 1 - Mechanism of Emulsion Formation



Photomicrographs of emulsions formed with two different homogenizing pressures. (1) Upper: ΔP = 2600 psi., (2) lower: 200 psi. Scale: 3 microns/division. Circle is scaled to an 85-micron diameter to illustrate a spray drop of emulsion.

Figure 2 - Photomicrographs of Emulsions Showing Variation in Dispersion Size



(1) *The "emulsifier" operates at a constant flow of 65 gph; the combustor requires only 30 gph. The excess is recycled through this bypass line.*

(2) *This bypass section is used to establish flow rates before introducing fuel to the combustor.*

Figure 3 - Flow Diagram of Experimental In-Line Fuel Emulsification System

Figure 4 - T-63 Combustor Liner

Figure 5 - Exhaust Instrumentation Section

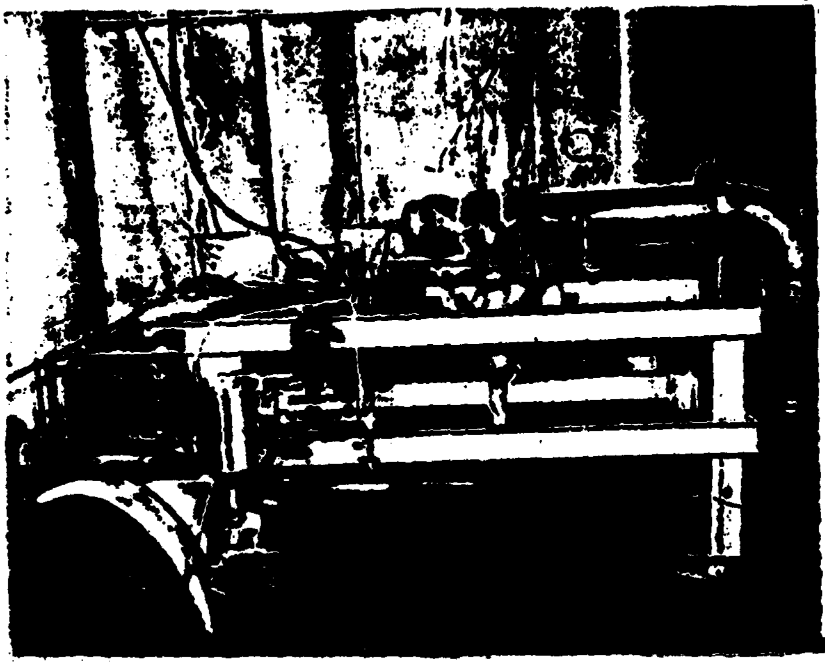


Figure 6

T-63 Combustor
Rig Installation

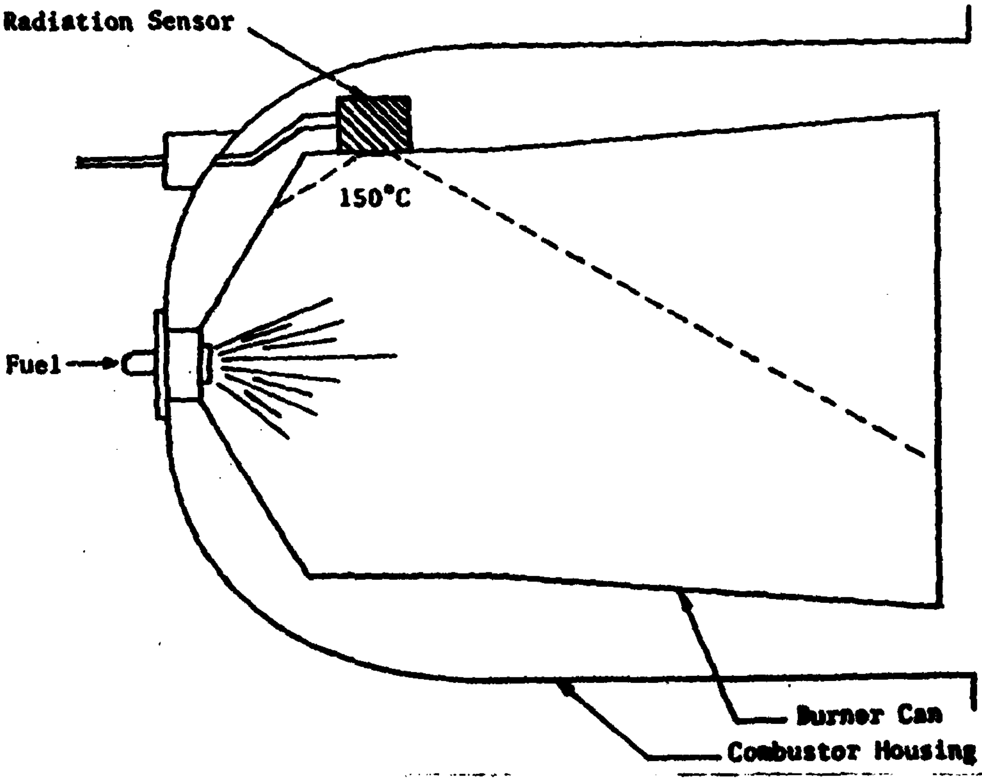


Figure 7 - Flame Radiation Measurement

* U. S. ARMY FUELS & LUBRICANTS RESEARCH LABORATORY
TURBINE COMBUSTOR FACILITY

--- STUDY OF FUEL EMULSIONS FOR THE REDUCTION OF EXHAUST PARTICULATES --
U.S. NAVY AIR ENGINEERING CENTER

DATE: 6/13 73 TIME: 10:16
COMBUSTOR SYSTEM: T-63 POWER POINT: 100%
TEST FUEL: JP5-P

***** EXPERIMENTAL TEST CONDITIONS *****

	AVERAGE	STD.DEV.	DESIRED	LAST SCAN
INLET AIR PRESSURE, PSIA	69.94	.41	76.20	69.80
INLET AIR TEMPERATURE, DEG F	522.74	1.26	524.00	522.38
AIR FLOW RATE, LBS/SEC	2.512	.012	2.660	2.516
FUEL FLOW RATE, LBS/MIN	2.990	.026	3.160	2.987
FUEL-AIR RATIO	.01984	.00019	.01980	.01979
AIR FLOW LOADING FACTOR	~~0.0000~~ 7.725	0.0000	1.0940	0.0000

FUEL PRESSURE= 0
FUEL TEMPERATURE= 83.5 DEG F

* BURNER OUTLET TEMPERATURE SURVEY *

BOT AVG=1744.0 DEG F
BOT HOT SPOT: TC# 8 = 1824 DEG F
BOT PATTERN FACTOR = .0658

	TC#	AVERAGE	STD DEV
OUTER ANNULUS	1	1797	19
	4	1820	13
	7	0	1
	10	1709	11
	13	0	32
CENTER ANNULUS	2	1776	19
	5	1796	12
	8	1824	13
	11	1550	14
	14	1747	11
INNER ANNULUS	3	1719	11
	6	0	26
	9	1682	22
	12	0	7
	15	1765	27

* EXHAUST CHEMISTRY *

CO.. .033 % CO2..4.50 % O2..16.2 % UBH.. 2.9 PPM <PROPANE>
NO.. 57.5 PPM NOX.. 61.5 PPM NO2.. 4.0 PPM <NOX-NO>
SMOKE NUMBER: 24.4

COMBUSTION EFFICIENCY, CALCULATED FROM EXHAUST CHEMISTRY: 99.6195 %
FUEL/AIR RATIO,CALCULATED FROM EXHAUST CHEMISTRY: .020028
REMARKS:

Figure 8 - Test Report of Experiment No. 1

* U. S. ARMY FUELS & LUBRICANTS RESEARCH LABORATORY
TURBINE COMBUSTOR FACILITY

--- STUDY OF FUEL EMULSIONS FOR THE REDUCTION OF EXHAUST PARTICULATES --
U.S. NAVY AIR ENGINEERING CENTER

DATE: 6/13 73 TIME: 11: 5
COMBUSTOR SYSTEM: T-63 POWER POINT: 100%
TEST FUEL: JP5-P *EMULSIFIED with 10% WATER*

***** EXPERIMENTAL TEST CONDITIONS *****

	AVERAGE	STD.DEV.	DESIRED	LAST SCAN
INLET AIR PRESSURE, PSIA	71.29	.32	76.20	71.70
INLET AIR TEMPERATURE, DEG F	523.70	1.05	524.00	522.30
AIR FLOW RATE, LBS/SEC	2.485	.010	2.660	2.492
FUEL FLOW RATE, LBS/MIN	3.355	.033	3.160	3.309
FUEL/AIR RATIO	.02251	.00026	.01980	.02267
AIR FLOW LOADING FACTOR	~~0.0000~~ 1.845	0.0000	1.0940	0.0000

FUEL PRESSURE= *900*
FUEL TEMPERATURE=112.0 DEG F

* BURNER OUTLET TEMPERATURE SURVEY *

BOT AVG=1705.3 DEG F
BOT HOT SPOT: TC# 5 = 1856 DEG F
BOT PATTERN FACTOR = .1276

	TC#	AVERAGE	STD DEV
OUTER ANNULUS	1	1779	16
	4	1843	15
	7	0	1
	10	1710	14
	13	1403	32
CENTER ANNULUS	2	1782	16
	5	1856	17
	8	1851	19
	11	1550	13
	14	1749	14
INNER ANNULUS	3	1736	14
	6	0	126
	9	1507	33
	12	0	12
	15	1612	46

* EXHAUST CHEMISTRY *

CO.. .036 % CO2..4.50 % O2..14.5 % UBH.. 7.4 PPM <PROPANE>
NO.. 49.0 PPM NOX.. 53.0 PPM NO2.. 4.0 PPM <NOX-NO>
SMOKE NUMBER:

COMBUSTION EFFICIENCY, CALCULATED FROM EXHAUST CHEMISTRY: 99.5610 %
FUEL/AIR RATIO,CALCULATED FROM EXHAUST CHEMISTRY: .021652
REMARKS: *17.0*

10% H_2O, 3000 PSI Emulsion pressure

Figure 9 - Test Report of Experiment No. 2

U. S. ARMY FUELS & LUBRICANTS RESEARCH LABORATORY
TURBINE COMBUSTOR FACILITY

** STUDY OF FUEL EMULSIONS FOR THE REDUCTION OF EXHAUST PARTICULATES **
U.S. NAVY AIR ENGINEERING CENTER

DATE: 6/13/78 TIME: 11:31
COMBUSTOR SYSTEM: T-63 POWER POINT: 100%
TEST FUEL: JP5-P EMULSIFIED WITH 10% WATER

***** EXPERIMENTAL TEST CONDITIONS *****

	AVERAGE	STD.DEV.	DESIRED	LAST SCAN
INLET AIR PRESSURE, PSIA	71.89	.37	76.20	71.50
INLET AIR TEMPERATURE, DEG F	523.92	1.32	524.00	524.11
AIR FLOW RATE, LBS/SEC	2.474	.012	2.660	2.473
FUEL FLOW RATE, LBS/MIN	3.327	.028	3.160	3.317
FUEL/AIR RATIO	.02241	.00022	.01986	.02236
AIR FLOW LOADING FACTOR	~~0.0000~~ 1.079	0.0000	1.0940	0.0000

FUEL PRESSURE= 3000
FUEL TEMPERATURE=123.3 DEG F

* BURNER OUTLET TEMPERATURE SURVEY *

BOT AVG=1703.4 DEG F
BOT HOT SPOT: TC# 5 = 1837 DEG F
BOT PATTERN FACTOR = .1137

	TC#	AVERAGE	STD DEV
OUTER ANNULUS	1	1758	28
	4	1829	18
	7	0	1
	10	1706	14
	13	1498	26
CENTER ANNULUS	2	1778	28
	5	1837	22
	8	1827	19
	11	1563	16
	14	1742	13
INNER ANNULUS	3	1725	14
	6	0	135
	9	0	70
	12	0	15
	15	1474	53

* EXHAUST CHEMISTRY *

CO.. .040 % CO2..4.50 % O2..14.6 % UBH.. 6.8 PPM (PROPANE)
NO.. 45.3 PPM NOX.. 55.5 PPM NO2..13.5 PPM (NOX-NO)
SMOKE NUMBER: 16.9

COMBUSTION EFFICIENCY, CALCULATED FROM EXHAUST CHEMISTRY: 99.5254 %
FUEL/AIR RATIO,CALCULATED FROM EXHAUST CHEMISTRY: .021554
REMARKS:
3000 PSI Homogenizer pressure

Figure 10 - Test Report of Experiment No. 3

U. S. ARMY FUELS & LUBRICANTS RESEARCH LABORATORY
TURBINE COMBUSTOR FACILITY

** STUDY OF FUEL EMULSIONS FOR THE REDUCTION OF EXHAUST PARTICULATES **
U.S. NAVY AIR ENGINEERING CENTER

DATE: 6/13/78 TIME: 11:55
COMBUSTOR SYSTEM: T-63 POWER POINT: 100%
TEST FUEL: JP5-P EMULSIFIED WITH 10% WATER

***** EXPERIMENTAL TEST CONDITIONS *****

	AVERAGE	STD.DEV.	DESIRED	LAST SCAN
INLET AIR PRESSURE, PSIA	72.28	.43	76.20	72.80
INLET AIR TEMPERATURE, DEG F	522.79	1.22	524.00	523.68
AIR FLOW RATE, LBS/SEC	2.467	.013	2.660	2.443
FUEL FLOW RATE, LBS/MIN	3.284	.038	3.160	3.293
FUEL/AIR RATIO	.02219	.00022	.01980	.02247
AIR FLOW LOADING FACTOR	~~0.0000~~ 1.069	0.0000	1.0940	0.0000

FUEL PRESSURE= 600
FUEL TEMPERATURE= 97.4 DEG F

* BURNER OUTLET TEMPERATURE SURVEY *

BOT AVG=1693.4 DEG F
BOT HOT SPOT: TC# 5 = 1808 DEG F
BOT PATTERN FACTOR = .0976

	TC#	AVERAGE	STD DEV
OUTER ANNULUS	1	1719	14
	4	1796	13
	7	0	1
	10	1664	12
	13	1515	10
CENTER ANNULUS	2	1760	14
	5	1808	16
	8	1787	15
	11	1555	15
	14	1720	12
INNER ANNULUS	3	1671	14
	6	0	118
	9	0	198
	12	0	12
	15	1633	42

* EXHAUST CHEMISTRY *

CO.. .040 % CO2..4.50 % O2..14.8 % UBH.. 6.0 PPM (PROPANE)
NO.. 43.5 PPM NOX.. 54.5 PPM NO2..11.0 PPM (NOX-NO)
SMOKE NUMBER: 17.3

COMBUSTION EFFICIENCY, CALCULATED FROM EXHAUST CHEMISTRY: 99.5311 %
FUEL/AIR RATIO,CALCULATED FROM EXHAUST CHEMISTRY: .021412
REMARKS:
600 PSi Homogenizer Pressure

Figure 11 - Test Report of Experiment No. 4

U. S. ARMY FUELS & LUBRICANTS RESEARCH LABORATORY
TURBINE COMBUSTOR FACILITY

--- STUDY OF FUEL EMULSIONS FOR THE REDUCTION OF EXHAUST PARTICULATES ---
U.S. NAVY AIR ENGINEERING CENTER

DATE: 6/18/75 TIME: 9:40
COMBUSTOR SYSTEM: T-63 POWER POINT: 100%
TEST FUEL: JP5-P [redacted]

***** EXPERIMENTAL TEST CONDITIONS *****

	AVERAGE	STD.DEV.	DESIRED	LAST SCAN
INLET AIR PRESSURE, PSIA	71.26	.49	76.20	72.30
INLET AIR TEMPERATURE, DEG F	525.33	1.51	524.00	523.46
AIR FLOW RATE, LBS/SEC	2.509	.017	2.660	2.489
FUEL FLOW RATE, LBS/MIN	2.975	.027	3.160	3.014
FUEL/AIR RATIO	.01976	.00023	.01980	.02018
AIR FLOW LOADING FACTOR	~~0.0000~~ 1.789	0.0000	~~0.2500~~ 1.0990	0.0000

FUEL PRESSURE= 0
FUEL TEMPERATURE= 87.4 DEG F

* BURNER OUTLET TEMPERATURE SURVEY *

BOT AVG=1653.4 DEG F
BOT HOT SPOT: TC# 8 = 1827 DEG F
BOT PATTERN FACTOR = .1541

	TC#	AVERAGE	STD DEV
OUTER ANNULUS	1	1648	36
	4	1773	12
	7	1759	15
	10	1511	64
	13	1350	80
CENTER ANNULUS	2	1744	36
	5	1827	15
	8	1827	13
	11	1572	13
	14	1736	10
INNER ANNULUS	3	1565	11
	6	1639	22
	9	0	117
	12	0	75
	15	1543	72

* EXHAUST CHEMISTRY *

CO.. .032 % CO2..4.33 % O2..15.2 % UBH.. 3.6 PPM (PROPANE)
NO.. 52.3 PPM NOX.. 58.0 PPM NO2.. 5.5 PPM (NOX-NO)
SMOKE NUMBER: 25.5

COMBUSTION EFFICIENCY, CALCULATED FROM EXHAUST CHEMISTRY: 99.6121 %
FUEL/AIR RATIO, CALCULATED FROM EXHAUST CHEMISTRY: .020339
REMARKS:

Figure 12 - Test Report of Experiment No. 5

U. S. ARMY FUELS & LUBRICANTS RESEARCH LABORATORY
TURBINE COMBUSTOR FACILITY

--- STUDY OF FUEL EMULSIONS FOR THE REDUCTION OF EXHAUST PARTICULATES ---
U.S. NAVY AIR ENGINEERING CENTER

DATE: 6/18/75 TIME: 10:10
COMBUSTOR SYSTEM: T-63 POWER POINT: 100%
TEST FUEL: JP5-P EMULSIFIED WITH 10% WATER

***** EXPERIMENTAL TEST CONDITIONS *****

	AVERAGE	STD.DEV.	DESIRED	LAST SCAN
INLET AIR PRESSURE, PSIA	71.30	.42	76.20	71.10
INLET AIR TEMPERATURE, DEG F	525.83	1.01	524.00	526.70
AIR FLOW RATE, LBS/SEC	2.495	.012	2.660	2.483
FUEL FLOW RATE, LBS/MIN	3.273	.034	3.330	3.240
FUEL/AIR RATIO	.02187	.00026	.02200	.02175
AIR FLOW LOADING FACTOR	~~0.0000~~ 1.098	0.0000	1.0940	0.0000

FUEL PRESSURE= 0
FUEL TEMPERATURE=122.4 DEG F

* BURNER OUTLET TEMPERATURE SURVEY *

BOT AVG=1704.5 DEG F
BOT HOT SPOT: TC# 5 = 1838 DEG F
BOT PATTERN FACTOR = .1134

	TC#	AVERAGE	STD DEV
OUTER ANNULUS	1	1759	36
	4	1785	11
	7	1767	17
	10	1489	40
	13	0	50
CENTER ANNULUS	2	1741	36
	5	1838	13
	8	1826	15
	11	1583	13
	14	1743	14
INNER ANNULUS	3	1635	13
	6	0	103
	9	0	159
	12	0	109
	15	1583	120

* EXHAUST CHEMISTRY *

CO.. .038 % CO2..4.42 % O2..15.1 % UBH.. 5.3 PPM (PROPANE)
NO.. 44.5 PPM NOX.. 51.5 PPM NO2.. 7.0 PPM (NOX-NO)
SMOKE NUMBER: 18.5

COMBUSTION EFFICIENCY, CALCULATED FROM EXHAUST CHEMISTRY: 99.5464 %
FUEL/AIR RATIO, CALCULATED FROM EXHAUST CHEMISTRY: .020851
REMARKS: 1% Surfactant

Figure 13 - Test Report of Experiment No. 6

U. S. ARMY FUELS & LUBRICANTS RESEARCH LABORATORY
TURBINE COMBUSTOR FACILITY

*** STUDY OF FUEL EMULSIONS FOR THE REDUCTION OF EXHAUST PARTICULATES ***
U.S. NAVY AIR ENGINEERING CENTER

DATE 6/19/75 TIME: 11:22
COMBUSTOR SYSTEM: T-63 POWER POINT: 100%
TEST FUEL: JP5-P EMULSIFIED WITH 10% WATER

***** EXPERIMENTAL TEST CONDITIONS *****

	AVERAGE	STD.DEV.	DESIRED	LAST SCAN
INLET AIR PRESSURE, PSIA	72.77	.88	76.20	71.60
INLET AIR TEMPERATURE, DEG F	525.60	.95	524.00	523.89
AIR FLOW RATE, LBS/SEC	2.458	.017	2.660	2.497
FUEL FLOW RATE, LBS/MIN	3.289	.031	3.330	3.335
FUEL/AIR RATIO	.02231	.00026	.02200	.02226
AIR FLOW LOADING FACTOR	~~0.0000~~ 1.060	0.0000	1.0940	0.0000

FUEL PRESSURE= 0
FUEL TEMPERATURE=123.7 DEG F

* BURNER OUTLET TEMPERATURE SURVEY *

BOT AVG=1719.1 DEG F
BOT HOT SPOT: TC# 5 = 1860 DEG F
BOT PATTERN FACTOR = .1181

	TC#	AVERAGE	STD DEV
OUTER ANNULUS	1	1781	20
	4	1808	19
	7	1782	18
	10	1573	29
	13	0	13
CENTER ANNULUS	2	1762	20
	5	1860	21
	8	1840	29
	11	1591	18
	14	1766	16
INNER ANNULUS	3	1605	16
	6	0	111
	9	0	55
	12	0	52
	15	1541	60

* EXHAUST CHEMISTRY *

CO.. .033 % CO2..4.50 % O2..14.7 % UBH.. 4.8 PPM <PROPANE>
NO.. 48.8 PPM NOX.. 56.2 PPM NO2.. 8.2 PPM <NOX-NO>
SMOKE NUMBER:

COMBUSTION EFFICIENCY, CALCULATED FROM EXHAUST CHEMISTRY: 99.6096 %
FUEL AIR RATIO,CALCULATED FROM EXHAUST CHEMISTRY: .021495
REMARKS: 0.5% Surfactant

Figure 14 - Test Report of Experiment No. 7

U. S. ARMY FUELS & LUBRICANTS RESEARCH LABORATORY
TURBINE COMBUSTOR FACILITY

*** STUDY OF FUEL EMULSIONS FOR THE REDUCTION OF EXHAUST PARTICULATES ***
U.S. NAVY AIR ENGINEERING CENTER

DATE: 6/19 75 TIME: 11:11
COMBUSTOR SYSTEM: T-63 POWER POINT: 100%
TEST FUEL: JP5-P

***** EXPERIMENTAL TEST CONDITIONS *****

	AVERAGE	STD.DEV.	DESIRED	LAST SCAN
INLET AIR PRESSURE, PSIA	71.22	.27	76.20	71.10
INLET AIR TEMPERATURE, DEG F	525.10	.95	524.00	524.54
AIR FLOW RATE, LBS/SEC	2.495	.014	2.660	2.477
FUEL FLOW RATE, LBS/MIN	2.955	.036	3.160	2.984
FUEL/AIR RATIO	.01973	.00028	.01980	.02008
AIR FLOW LOADING FACTOR	1.0998	.0064	1.0940	1.0930

FUEL PRESSURE= 0
FUEL TEMPERATURE= 87.9 DEG F

* BURNER OUTLET TEMPERATURE SURVEY *

BOT AVG=1646.2 DEG F
BOT HOT SPOT: TC# 8 = 1796 DEG F
BOT PATTERN FACTOR = .1330

	TC#	AVERAGE	STD DEV
OUTER ANNULUS	1	1700	13
	4	1703	17
	7	1597	29
	10	1528	13
	13	1418	60
CENTER ANNULUS	2	1729	13
	5	1772	12
	8	1796	13
	11	1581	11
	14	1711	11
INNER ANNULUS	3	0	12
	6	0	120
	9	0	30
	12	0	80
	15	1573	93

* EXHAUST CHEMISTRY *

CO.. .033 % CO2..4.30 % O2..16.3 % UBH.. 3.4 PPM <PROPANE>
NO.. 52.6 PPM NOX.. 58.5 PPM NO2.. 5.9 PPM <NOX-NO>
SMOKE NUMBER: 27.1

COMBUSTION EFFICIENCY, CALCULATED FROM EXHAUST CHEMISTRY: 99.6000 %
FUEL AIR RATIO,CALCULATED FROM EXHAUST CHEMISTRY: .019526
REMARKS:

Figure 15 - Test Report of Experiment No. 8

U. S. ARMY FUELS & LUBRICANTS RESEARCH LABORATORY
TURBINE COMBUSTOR FACILITY

*** STUDY OF FUEL EMULSIONS FOR THE REDUCTION OF EXHAUST PARTICULATES ***
U.S. NAVY AIR ENGINEERING CENTER

DATE: 6/23/75 TIME: 10:58
COMBUSTOR SYSTEM: T-63 POWER POINT: 100%
TEST FUEL: JP5-P

***** EXPERIMENTAL TEST CONDITIONS *****

	AVERAGE	STD.DEV.	DESIRED	LAST SCAN
INLET AIR PRESSURE, PSIA	72.83	.23	76.20	72.90
INLET AIR TEMPERATURE, DEG F	526.35	1.18	524.00	526.70
AIR FLOW RATE, LBS/SEC	2.528	.010	2.660	2.516
FUEL FLOW RATE, LBS/MIN	3.038	.030	3.160	3.026
FUEL/AIR RATIO	.02003	.00022	.01980	.02005
AIR FLOW LOADING FACTOR	1.0903	.0053	1.0940	1.0840

FUEL PRESSURE= 0
FUEL TEMPERATURE= 85.7 DEG F

* BURNER OUTLET TEMPERATURE SURVEY *

BOT AVG=1654.2 DEG F
BOT HOT SPOT: TC# 8 = 1828 DEG F
BOT PATTERN FACTOR = .1543

	TC#	AVERAGE	STD DEV
OUTER ANNULUS	1	1757	17
	4	1547	42
	7	0	144
	10	1633	15
	13	0	11
CENTER ANNULUS	2	1773	17
	5	1792	29
	8	1828	13
	11	1624	14
	14	1769	12
INNER ANNULUS	3	0	14
	6	0	160
	9	0	196
	12	1030	119
	15	1788	13

* EXHAUST CHEMISTRY *

CO.. .032 % CO2..4.50 % O2..14.7 % UBH.. 2.2 PPM <PROPANE>
NO.. 58.0 PPM NOX.. 63.5 PPM NO2.. 5.5 PPM <NOX-NO>
SMOKE NUMBER: 27.6

COMBUSTION EFFICIENCY, CALCULATED FROM EXHAUST CHEMISTRY: 99.6344 %
FUEL/AIR RATIO,CALCULATED FROM EXHAUST CHEMISTRY: .021477
REMARKS:

Figure 16 - Test Report of Experiment No. 9

U. S. ARMY FUELS & LUBRICANTS RESEARCH LABORATORY
TURBINE COMBUSTOR FACILITY

*** STUDY OF FUEL EMULSIONS FOR THE REDUCTION OF EXHAUST PARTICULATES
U.S. NAVY AIR ENGINEERING CENTER

DATE: 6/23/75 TIME: 11:26
COMBUSTOR SYSTEM: T-63 POWER POINT: 100%
TEST FUEL: JP5-P

***** EXPERIMENTAL TEST CONDITIONS *****

	AVERAGE	STD.DEV.	DESIRED	LAST SCAN
INLET AIR PRESSURE, PSIA	72.00	.62	76.20	72.50
INLET AIR TEMPERATURE, DEG F	525.72	1.64	524.00	524.33
AIR FLOW RATE, LBS/SEC	2.529	.014	2.660	2.502
FUEL FLOW RATE, LBS/MIN	2.991	.056	3.160	3.073
FUEL/AIR RATIO	.01972	.00039	.01980	.02047
AIR FLOW LOADING FACTOR	1.1028	.0131	1.0940	1.0828

FUEL PRESSURE= 0
FUEL TEMPERATURE=125.8 DEG F

* BURNER OUTLET TEMPERATURE SURVEY *

BOT AVG=1701.0 DEG F
BOT HOT SPOT: TC# 8 = 1784 DEG F
BOT PATTERN FACTOR = .0706

	TC#	AVERAGE	STD DEV
OUTER ANNULUS	1	1714	17
	4	0	173
	7	0	1622
	10	1623	21
	13	0	82
CENTER ANNULUS	2	1731	17
	5	1750	29
	8	1784	15
	11	1565	18
	14	1720	16
INNER ANNULUS	3	0	14
	6	0	196
	9	0	205
	12	0	96
	15	1721	33

* EXHAUST CHEMISTRY *

CO.. .035 % CO2..4.23 % O2..15.0 % UBH.. 3.8 PPM <PROPANE>
NO.. 51.5 PPM NOX.. 58.3 PPM NO2.. 6.8 PPM <NOX-NO>
SMOKE NUMBER: 26.6

COMBUSTION EFFICIENCY, CALCULATED FROM EXHAUST CHEMISTRY: 99.5690 %
FUEL/AIR RATIO,CALCULATED FROM EXHAUST CHEMISTRY: .020307
REMARKS: Fuel + 2% Surfactant but no water
ΔP_N = 3000 psi

Figure 17 - Test Report of Experiment No. 10

U. S. ARMY FUELS & LUBRICANTS RESEARCH LABORATORY
TURBINE COMBUSTOR FACILITY

*** STUDY OF FUEL EMULSIONS FOR THE REDUCTION OF EXHAUST PARTICULATES **
U.S. NAVY AIR ENGINEERING CENTER

DATE: 6 25 78 TIME: 9: 8
COMBUSTOR SYSTEM: T-63 POWER POINT: 100%
TEST FUEL: JP5-P

***** EXPERIMENTAL TEST CONDITIONS *****

	AVERAGE	STD.DEV.	DESIRED	LAST SCAN
INLET AIR PRESSURE, PSIA	72.66	.20	76.20	72.40
INLET AIR TEMPERATURE, DEG F	524.20	1.88	524.03	524.11
AIR FLOW RATE, LBS/SEC	2.524	.013	2.660	2.530
FUEL FLOW RATE, LBS/MIN	2.999	.026	3.160	2.981
FUEL/AIR RATIO	.01981	.00020	.01980	.01964
AIR FLOW LOADING FACTOR	1.0896	.0063	1.0940	1.0962

FUEL PRESSURE= 0
FUEL TEMPERATURE= 86.1 DEG F

* BURNER OUTLET TEMPERATURE SURVEY *

BOT AVG=1662.1 DEG F
BOT HOT SPOT: TC# 8 = 1815 DEG F
BOT PATTERN FACTOR = .1343

	TC#	AVERAGE	STD DEV
OUTER ANNULUS	1	1778	12
	4	1512	60
	7	0	6
	10	1616	16
	13	1648	21
CENTER ANNULUS	2	1770	12
	5	0	450
	8	1815	11
	11	1591	11
	14	1746	11
INNER ANNULUS	3	1593	10
	6	0	58
	9	1667	14
	12	1453	35
	15	1757	22

* EXHAUST CHEMISTRY *

CO.. .032 % CO2..4.35 % O2..15.2 % UBH.. 3.4 PPM <PROPANE>
NO.. 55.4 PPM NOX.. 61.5 PPM NO2.. 6.1 PPM <NOX-NO>
SMOKE NUMBER: 27.2

COMBUSTION EFFICIENCY, CALCULATED FROM EXHAUST CHEMISTRY: 99.6142 %
FUEL/AIR RATIO,CALCULATED FROM EXHAUST CHEMISTRY: .020502
REMARKS:

Figure 18 - Test Report of Experiment No. 11

U. S. ARMY FUELS & LUBRICANTS RESEARCH LABORATORY
TURBINE COMBUSTOR FACILITY

** STUDY OF FUEL EMULSIONS FOR THE REDUCTION OF EXHAUST PARTICULATES **
U.S. NAVY AIR ENGINEERING CENTER

DATE: 6/25/7 TIME: 9:37
COMBUSTOR SYSTEM: T-63 POWER POINT: 100%
TEST FUEL: JP5-P EMULSIFIED WITH 10% WATER

***** EXPERIMENTAL TEST CONDITIONS *****

	AVERAGE	STD.DEV.	DESIRED	LAST SCAN
INLET AIR PRESSURE, PSIA	72.56	.28	76.20	72.50
INLET AIR TEMPERATURE, DEG F	524.85	1.18	524.00	525.62
AIR FLOW RATE, LBS/SEC	2.516	.012	2.660	2.508
FUEL FLOW RATE, LBS/MIN	3.294	.034	3.330	3.377
FUEL/AIR RATIO	.02183	.00027	.02200	.02244
AIR FLOW LOADING FACTOR	1.0879	.0075	1.0940	1.0862

FUEL PRESSURE= 0
FUEL TEMPERATURE=118.9 DEG F

* BURNER OUTLET TEMPERATURE SURVEY *

BOT AVG=1642.6 DEG F
BOT HOT SPOT: TC# 8 = 1820 DEG F
BOT PATTERN FACTOR = .1590

	TC#	AVERAGE	STD DEV
OUTER ANNULUS	1	1783	14
	4	1500	68
	7	0	3
	10	1615	21
	13	1601	14
CENTER ANNULUS	2	1764	14
	5	0	195
	8	1820	14
	11	1596	14
	14	1741	12
INNER ANNULUS	3	0	11
	6	0	178
	9	1610	34
	12	1282	73
	15	1755	18

* EXHAUST CHEMISTRY *

CO.. .040 % CO2..4.40 % O2..14.4 % UBH.. 5.7 PPM <PROPANE>
NO.. 45.0 PPM NOX.. 52.5 PPM NO2.. 7.5 PPM <NOX-NO>
SMOKE NUMBER: 18.9

COMBUSTION EFFICIENCY, CALCULATED FROM EXHAUST CHEMISTRY: 99.5225 %
FUEL/AIR RATIO,CALCULATED FROM EXHAUST CHEMISTRY: .021490
REMARKS: 3000 P.S.I. 3% emulsifier

Figure 19 - Test Report of Experiment No. 12

U. S. ARMY FUELS & LUBRICANTS RESEARCH LABORATORY
TURBINE COMBUSTOR FACILITY

** STUDY OF FUEL EMULSIONS FOR THE REDUCTION OF EXHAUST PARTICULATES **
U.S. NAVY AIR ENGINEERING CENTER

DATE: 6/25/75 TIME: 10:43
COMBUSTOR SYSTEM: T-63 POWER POINT: 100%
TEST FUEL: JP5-P EMULSIFIED WITH 5% WATER

***** EXPERIMENTAL TEST CONDITIONS *****

	AVERAGE	STD.DEV.	DESIRED	LAST SCAN
INLET AIR PRESSURE, PSIA	72.36	.26	76.20	72.50
INLET AIR TEMPERATURE, DEG F	524.53	1.27	524.00	522.82
AIR FLOW RATE, LBS/SEC	2.507	.013	2.660	2.490
FUEL FLOW RATE, LBS/MIN	3.234	.029	3.210	3.266
FUEL/AIR RATIO	.02151	.00025	.02120	.02186
AIR FLOW LOADING FACTOR	1.0869	.0076	1.0940	1.0767

FUEL PRESSURE= 0
FUEL TEMPERATURE=121.1 DEG F

* BURNER OUTLET TEMPERATURE SURVEY *

BOT AVG=1720.2 DEG F
BOT HOT SPOT: TC# 8 = 1856 DEG F
BOT PATTERN FACTOR = .1138

	TC#	AVERAGE	STD DEV
OUTER ANNULUS	1	1821	16
	4	1579	37
	7	0	3
	10	1661	14
	13	1650	25
CENTER ANNULUS	2	1798	16
	5	0	111
	8	1856	11
	11	1639	12
	14	1774	10
INNER ANNULUS	3	0	10
	6	0	19
	9	1626	26
	12	0	130
	15	1798	15

* EXHAUST CHEMISTRY *

CO.. .033 % CO2..4.52 % O2..14.6 % UBH.. 3.4 PPM (PROPANE)
NO.. 51.7 PPM NOX.. 59.5 PPM NO2.. 7.8 PPM (NOX-NO)
SMOKE NUMBER: 21.4

COMBUSTION EFFICIENCY, CALCULATED FROM EXHAUST CHEMISTRY: 99.6193 %
FUEL/AIR RATIO, CALCULATED FROM EXHAUST CHEMISTRY: .021598
REMARKS: 3000 P.S.I. 2% surf.

Figure 20 - Test Report of Experiment No. 13

U. S. ARMY FUELS & LUBRICANTS RESEARCH LABORATORY
TURBINE COMBUSTOR FACILITY

** STUDY OF FUEL EMULSIONS FOR THE REDUCTION OF EXHAUST PARTICULATES *
U.S. NAVY AIR ENGINEERING CENTER

DATE: 6/25/75 TIME: 11:46
COMBUSTOR SYSTEM: T-63 POWER POINT: 100%
TEST FUEL: JP5-P EMULSIFIED WITH 3% WATER

***** EXPERIMENTAL TEST CONDITIONS *****

	AVERAGE	STD.DEV.	DESIRED	LAST SCAN
INLET AIR PRESSURE, PSIA	71.53	.16	76.20	71.30
INLET AIR TEMPERATURE, DEG F	524.96	.95	524.00	524.33
AIR FLOW RATE, LBS/SEC	2.503	.010	2.660	2.521
FUEL FLOW RATE, LBS/MIN	3.166	.029	3.180	3.216
FUEL/AIR RATIO	.02108	.00020	.02100	.02126
AIR FLOW LOADING FACTOR	1.0983	.0047	1.0940	1.1095

FUEL PRESSURE= 0
FUEL TEMPERATURE=125.4 DEG F

* BURNER OUTLET TEMPERATURE SURVEY *

BOT AVG=1696.3 DEG F
BOT HOT SPOT: TC# 8 = 1825 DEG F
BOT PATTERN FACTOR = .1099

	TC#	AVERAGE	STD DEV
OUTER ANNULUS	1	1784	14
	4	1582	34
	7	0	11
	10	1590	15
	13	1587	36
CENTER ANNULUS	2	1771	14
	5	0	322
	8	1825	11
	11	1608	13
	14	1747	11
INNER ANNULUS	3	0	10
	6	0	12
	9	0	31
	12	0	162
	15	1771	15

* EXHAUST CHEMISTRY *

CO.. .035 % CO2..4.40 % O2..14.5 % UBH.. 3.6 PPM (PROPANE)
NO.. 50.5 PPM NOX.. 57.5 PPM NO2.. 7.0 PPM (NOX-NO)
SMOKE NUMBER: 23.0

COMBUSTION EFFICIENCY, CALCULATED FROM EXHAUST CHEMISTRY: 99.5072 %
FUEL/AIR RATIO, CALCULATED FROM EXHAUST CHEMISTRY: .021314
REMARKS: 3000 P.S.I. 1% surf.

Figure 21 - Test Report of Experiment No. 14

U. S. ARMY FUELS & LUBRICANTS RESEARCH LABORATORY
TURBINE COMBUSTOR FACILITY

*** STUDY OF FUEL EMULSIONS FOR THE REDUCTION OF EXHAUST PARTICULATES ***
U.S. NAVY AIR ENGINEERING CENTER

DATE: 6/25/75 TIME: 12:32
COMBUSTOR SYSTEM: T-63 POWER POINT: 100%
TEST FUEL: JP5-P EMULSIFIED WITH 5% WATER

***** EXPERIMENTAL TEST CONDITIONS *****

	AVERAGE	STD.DEV.	DESIRED	LAST SCAN
INLET AIR PRESSURE, PSIA	72.31	.17	76.20	72.10
INLET AIR TEMPERATURE, DEG F	524.35	1.26	524.00	524.76
AIR FLOW RATE, LBS/SEC	2.494	.011	2.660	2.482
FUEL FLOW RATE, LBS/MIN	3.166	.034	3.160	3.180
FUEL/AIR RATIO	.02116	.00025	.02090	.02135
AIR FLOW LOADING FACTOR	1.0819	.0049	1.0940	1.0804

FUEL PRESSURE= 0
FUEL TEMPERATURE=125.0 DEG F

* BURNER OUTLET TEMPERATURE SURVEY *

BOT AVG=1687.1 DEG F
BOT HOT SPOT: TC# 8 = 1822 DEG F
BOT PATTERN FACTOR = .1157

	TC#	AVERAGE	STD DEV
OUTER ANNULUS	1	1763	21
	4	1576	28
	7	0	14
	10	1565	29
	13	1586	17
CENTER ANNULUS	2	1771	21
	5	0	2386
	8	1822	11
	11	1594	13
	14	1742	10
INNER ANNULUS	3	0	11
	6	0	12
	9	0	119
	12	0	58
	15	1765	14

* EXHAUST CHEMISTRY *

CO.. .035 % CO2..4.37 % O2..14.3 % UBH.. 3.6 PPM <PROPANE>
NO.. 52.5 PPM NOX.. 58.5 PPM NO2.. 6.0 PPM <NOX-NO>
SMOKE NUMBER: 24.0

COMBUSTION EFFICIENCY, CALCULATED FROM EXHAUST CHEMISTRY: 99.5030 %
FUEL/AIR RATIO,CALCULATED FROM EXHAUST CHEMISTRY: .021470
REMARKS: 3000 P.S.I. 1/2% emul.

Figure 22 - Test Report of Experiment No. 15

U. S. ARMY FUELS & LUBRICANTS RESEARCH LABORATORY
TURBINE COMBUSTOR FACILITY

*** STUDY OF FUEL EMULSIONS FOR THE REDUCTION OF EXHAUST PARTICULATES ***
U.S. NAVY AIR ENGINEERING CENTER

DATE: 6/27/75 TIME: 9:24
COMBUSTOR SYSTEM: T-63 POWER POINT: 100%
TEST FUEL: JP5-HA EMULSIFIED WITH 0% WATER

***** EXPERIMENTAL TEST CONDITIONS *****

	AVERAGE	STD.DEV.	DESIRED	LAST SCAN
INLET AIR PRESSURE, PSIA	71.54	.19	76.20	71.60
INLET AIR TEMPERATURE, DEG F	524.98	1.32	524.00	524.11
AIR FLOW RATE, LBS/SEC	2.498	.012	2.660	2.510
FUEL FLOW RATE, LBS/MIN	2.980	.039	3.160	3.027
FUEL/AIR RATIO	.01988	.00026	.01980	.02010
AIR FLOW LOADING FACTOR	1.0960	.0050	1.0940	1.0996

FUEL PRESSURE= 0
FUEL TEMPERATURE= 89.7 DEG F

* BURNER OUTLET TEMPERATURE SURVEY *

BOT AVG=1700.5 DEG F
BOT HOT SPOT: TC# 8 = 1823 DEG F
BOT PATTERN FACTOR = .1042

	TC#	AVERAGE	STD DEV
OUTER ANNULUS	1	1791	12
	4	1730	17
	7	0	4
	10	1629	11
	13	1648	10
CENTER ANNULUS	2	1773	12
	5	1716	12
	8	1823	10
	11	1583	12
	14	1741	10
INNER ANNULUS	3	1668	11
	6	0	16
	9	1602	10
	12	0	9
	15	1702	16

* EXHAUST CHEMISTRY *

CO.. .033 % CO2..4.42 % O2..15.0 % UBH.. 2.5 PPM <PROPANE>
NO.. 60.5 PPM NOX.. 66.5 PPM NO2.. 6.0 PPM <NOX-NO>
SMOKE NUMBER: 33.6

COMBUSTION EFFICIENCY, CALCULATED FROM EXHAUST CHEMISTRY: 99.6009 %
FUEL/AIR RATIO,CALCULATED FROM EXHAUST CHEMISTRY: .020795
REMARKS:

Figure 23 - Test Report of Experiment No. 16

U.S. ARMY FUELS & LUBRICANTS RESEARCH LABORATORY
TURBINE COMBUSTOR FACILITY

*** NAVY JP-5 FUEL EMULSIONS FOR THE REDUCTION OF EXHAUST PARTICULATES ***
U.S. NAVY AIR ENGINEERING CENTER

DATE: [illegible] TIME: 9:57
COMBUSTOR SYSTEM: T-63 POWER POINT: 100%
TEST FUEL: JP5-NA EMULSIFIED WITH 10% WATER

***** EXPERIMENTAL TEST CONDITIONS *****

	AVERAGE	STD.DEV.	DESIRED	LAST SCAN
INLET AIR PRESSURE, PSIA	71.35	.23	76.20	71.90
INLET AIR TEMPERATURE, DEG F	526.60	1.39	524.00	525.84
AIR FLOW RATE, LBS/SEC	2.436	.012	2.660	2.460
FUEL FLOW RATE, LBS/MIN	3.299	.032	3.360	3.267
FUEL/AIR RATIO	.02212	.00025	.02220	.02213
AIR FLOW LOADING FACTOR	1.0944	.0067	1.0940	1.0742

FUEL PRESSURE= 0
FUEL TEMPERATURE=120.7 DEG F

* BURNER OUTLET TEMPERATURE SURVEY *

BOT AVG=1696.7 DEG F
BOT HOT SPOT: TC# 8 = 1854 DEG F
BOT PATTERN FACTOR = .1341

	TC#	AVERAGE	STD DEV
OUTER ANNULUS	1	1792	13
	4	1687	20
	7	0	2
	10	1596	14
	13	1659	11
CENTER ANNULUS	2	1763	13
	5	1751	12
	8	1854	12
	11	1615	13
	14	1747	10
INNER ANNULUS	3	1577	12
	6	0	153
	9	1593	19
	12	0	12
	15	1728	12

* EXHAUST CHEMISTRY *

CO.. .039 % CO2..4.40 % O2..14.5 % UBH.. 5.3 PPM (PROPANE)
NO.. 48.5 PPM NOX.. 54.5 PPM NO2.. 6.0 PPM (NOX-NO)
SMOKE NUMBER: 23.8

COMBUSTION EFFICIENCY, CALCULATED FROM EXHAUST CHEMISTRY: 99.5286 %
FUEL/AIR RATIO,CALCULATED FROM EXHAUST CHEMISTRY: .021304
REMARKS:
3000 P.S.I. 2% surf.

Figure 24 - Test Report of Experiment No. 17

U.S. ARMY FUELS & LUBRICANTS RESEARCH LABORATORY
TURBINE COMBUSTOR FACILITY

*** NAVY JP-5 FUEL EMULSIONS FOR THE REDUCTION OF EXHAUST PARTICULATES
U.S. NAVY AIR ENGINEERING CENTER

DATE: 6 27 75 TIME: 11: 0
COMBUSTOR SYSTEM: T-63 POWER POINT: 100%
TEST FUEL: JP5-NONEMULSIFIED WITH 0% WATER

***** EXPERIMENTAL TEST CONDITIONS *****

	AVERAGE	STD.DEV.	DESIRED	LAST SCAN
INLET AIR PRESSURE, PSIA	70.66	.50	76.20	71.20
INLET AIR TEMPERATURE, DEG F	522.96	1.33	524.00	519.36
AIR FLOW RATE, LBS/SEC	2.487	.015	2.660	2.497
FUEL FLOW RATE, LBS/MIN	2.983	.049	3.160	3.000
FUEL/AIR RATIO	.01999	.00035	.01980	.02002
AIR FLOW LOADING FACTOR	1.1037	.0112	1.0940	1.0976

FUEL PRESSURE= 0
FUEL TEMPERATURE= 90.4 DEG F

* BURNER OUTLET TEMPERATURE SURVEY *

BOT AVG=1673.3 DEG F
BOT HOT SPOT: TC# 8 = 1804 DEG F
BOT PATTERN FACTOR = .1137

	TC#	AVERAGE	STD DEV
OUTER ANNULUS	1	1784	21
	4	1652	29
	7	0	21
	10	1552	30
	13	1641	14
CENTER ANNULUS	2	1770	21
	5	1610	71
	8	1804	16
	11	1577	17
	14	1736	13
INNER ANNULUS	3	1540	16
	6	0	125
	9	0	89
	12	0	28
	15	1732	15

* EXHAUST CHEMISTRY *

CO.. .036 % CO2..4.36 % O2..14.9 % UBH.. 3.2 PPM (PROPANE)
NO.. 52.5 PPM NOX.. 60.0 PPM NO2.. 7.5 PPM (NOX-NO)
SMOKE NUMBER: 25.0

COMBUSTION EFFICIENCY, CALCULATED FROM EXHAUST CHEMISTRY: 99.5741 %
FUEL/AIR RATIO,CALCULATED FROM EXHAUST CHEMISTRY: .020775
REMARKS:

Figure 25 - Test Report of Experiment No. 18

U. S. ARMY FUELS & LUBRICANTS RESEARCH LABORATORY
TURBINE COMBUSTOR FACILITY

STUDY OF FUEL EMULSIONS FOR THE REDUCTION OF EXHAUST PARTICULATES -
U.S. NAVY AIR ENGINEERING CENTER

DATE: 6 27 75 TIME: 11: 0
COMBUSTOR SYSTEM: T-63 POWER POINT: 100%
TEST FUEL: JP5-HBREMULSIFIED WITH 10% WATER

***** EXPERIMENTAL TEST CONDITIONS *****

	AVERAGE	STD.DEV.	DESIRED	LAST SCAN
INLET AIR PRESSURE, PSIA	71.60	.26	76.20	7..80
INLET AIR TEMPERATURE, DEG F	524.34	1.46	524.00	524.11
AIR FLOW RATE, LBS/SEC	2.474	.013	2.660	2.468
FUEL FLOW RATE, LBS/MIN	3.300	.039	3.360	3.300
FUEL/AIR RATIO	.02223	.00033	.02220	.02220
AIR FLOW LOADING FACTOR	1.0840	.0073	1.0940	1.0703

FUEL PRESSURE= 0
FUEL TEMPERATURE=121.1 DEG F

* BURNER OUTLET TEMPERATURE SURVEY *

BOT AVG=1652.5 DEG F
BOT HOT SPOT: TC# 8 = 1817 DEG F
BOT PATTERN FACTOR = .1459

	TC#	AVERAGE	STD DEV
OUTER ANNULUS	1	1768	13
	4	1698	18
	7	0	1
	10	1544	13
	13	1620	9
CENTER ANNULUS	2	1758	13
	5	0	347
	8	1817	9
	11	1585	10
	14	1718	9
INNER ANNULUS	3	1542	13
	6	0	110
	9	0	49
	12	1419	10
	15	1700	11

* EXHAUST CHEMISTRY *

CO.. .041 % CO2..4.40 % O2..14.7 % UBH.. 6.4 PPM (PROPANE)
NO.. 45.0 PPM NOX.. 51.6 PPM NO2.. 6.6 PPM (NOX-NO)
SMOKE NUMBER: 15.4

COMBUSTION EFFICIENCY, CALCULATED FROM EXHAUST CHEMISTRY: 99.5011 %

3000 P.S.I. 2% emf.

Figure 26 - Test Report of Experiment No. 19

U. S. ARMY FUELS & LUBRICANTS RESEARCH LABORATORY
TURBINE COMBUSTOR FACILITY

*** STUDY OF FUEL EMULSIONS FOR THE REDUCTION OF EXHAUST PARTICULATES -
U.S. NAVY AIR ENGINEERING CENTER

DATE: 6 17 76 TIME: 9:27
COMBUSTOR SYSTEM: T-63 POWER POINT: 100%
TEST FUEL: JP5-P 0% WATER

***** EXPERIMENTAL TEST CONDITIONS *****

	AVERAGE	STD.DEV.	DESIRED	LAST SCAN
INLET AIR PRESSURE, PSIA	66.83	.49	76.20	65.90
INLET AIR TEMPERATURE, DEG F	523.42	1.14	524.00	523.46
AIR FLOW RATE, LBS/SEC	2.339	.012	2.660	2.306
FUEL FLOW RATE, LBS/MIN	2.810	.024	3.160	2.810
FUEL/AIR RATIO	.02002	.00019	.01980	.02031
AIR FLOW LOADING FACTOR	1.0975	.0093	1.0940	1.0973

FUEL PRESSURE= 305
FUEL TEMPERATURE=137.5 DEG F

* BURNER OUTLET TEMPERATURE SURVEY *

BOT AVG=$$$$$$ DEG F
BOT HOT SPOT: TC#12 = $$$$ DEG F
BOT PATTERN FACTOR = $$$$$$

	TC#	AVERAGE	STD DEV
OUTER ANNULUS	1	1783	18
	4	1637	84
	7	1601	28
	10	1576	17
	13	1614	16
CENTER ANNULUS	2	1874	18
	5	1794	16
	8	1804	14
	11	1658	16
	14	1771	11
INNER ANNULUS	3	1783	20
	6	1678	31
	9	1680	13
	12	449249	5626329
	15	1794	13

* EXHAUST CHEMISTRY *

CO.. .036 % CO2..4.50 % O2..14.5 % UBH..9.4 PPM (PROPANE)
NO.. 55.5 PPM NOX.. 62.0 PPM NO2.. 6.5 PPM (NOX-NO)
SMOKE NUMBER: 20.7

COMBUSTION EFFICIENCY, CALCULATED FROM EXHAUST CHEMISTRY: 99.5442
FUEL/AIR RATIO, CALCULATED FROM EXHAUST CHEMISTRY: .021253
REMARKS:

Figure 27 - Test Report of Experiment No. 20

U. S. ARMY FUELS & LUBRICANTS RESEARCH LABORATORY
TURBINE COMBUSTOR FACILITY

*** STUDY OF FUEL EMULSIONS FOR THE REDUCTION OF EXHAUST PARTICULATES *
U.S. NAVY AIR ENGINEERING CENTER

DATE: 6.17.76 TIME: 10: 1
COMBUSTOR SYSTEM: T-63 POWER POINT: 100%
TEST FUEL: JP5-P EMULSIFIED WITH 0% WATER

***** EXPERIMENTAL TEST CONDITIONS *****

	AVERAGE	STD.DEV.	DESIRED	LAST SCAN
INLET AIR PRESSURE, PSIA	67.02	.23	65.40	67.20
INLET AIR TEMPERATURE, DEG F	524.44	1.23	524.00	522.38
AIR FLOW RATE, LBS/SEC	2.327	.011	2.340	2.311
FUEL FLOW RATE, LBS/MIN	2.931	.029	2.960	2.899
FUEL/AIR RATIO	.02099	.00022	.02100	.02091
AIR FLOW LOADING FACTOR	1.0895	.0063	1.0940	1.0777

FUEL PRESSURE= 332
FUEL TEMPERATURE=135.3 DEG F

* BURNER OUTLET TEMPERATURE SURVEY *

BOT AVG=1713.9 DEG F
BOT HOT SPOT: TC# 2 = 1870 DEG F
BOT PATTERN FACTOR = .1316

	TC#	AVERAGE	STD DEV
OUTER ANNULUS	1	1780	15
	4	1730	36
	7	1554	34
	10	1584	10
	13	1588	11
CENTER ANNULUS	2	1870	15
	5	1776	14
	8	1790	10
	11	1672	16
	14	1765	9
INNER ANNULUS	3	1833	15
	6	1646	28
	9	1691	12
	12	1637	15
	15	1783	10

* EXHAUST CHEMISTRY *

CO.. .043 % CO2..4.37 % O2..14.7 % UBH.. 6.1 PPM <PROPANE>
NO.. 46.5 PPM NOX.. 55.5 PPM NO2.. 9.0 PPM <NOX-NO>
SMOKE NUMBER: 19.0

COMBUSTION EFFICIENCY, CALCULATED FROM EXHAUST CHEMISTRY: 99.4818
FUEL/AIR RATIO, CALCULATED FROM EXHAUST CHEMISTRY: .021049
REMARKS:

Figure 28 - Test Report of Experiment No. 21

U. S. ARMY FUELS & LUBRICANTS RESEARCH LABORATORY
TURBINE COMBUSTOR FACILITY

** STUDY OF FUEL EMULSIONS FOR THE REDUCTION OF EXHAUST PARTICULATES
U.S. NAVY AIR ENGINEERING CENTER

DATE: 6.17.76 TIME: 10:32
COMBUSTOR SYSTEM: T-63 POWER POINT: 100%
TEST FUEL: JP5-P EMULSIFIED WITH 10% WATER

***** EXPERIMENTAL TEST CONDITIONS *****

	AVERAGE	STD.DEV.	DESIRED	LAST SCAN
INLET AIR PRESSURE, PSIA	66.86	.15	65.40	66.90
INLET AIR TEMPERATURE, DEG F	524.02	1.34	524.00	525.62
AIR FLOW RATE, LBS/SEC	2.322	.013	2.340	2.336
FUEL FLOW RATE, LBS/MIN	3.103	.029	3.100	3.082
FUEL/AIR RATIO	.02227	.00025	.02170	.02195
AIR FLOW LOADING FACTOR	1.0900	.0069	1.0940	1.0961

FUEL PRESSURE= 347
FUEL TEMPERATURE=135.3 DEG F

* BURNER OUTLET TEMPERATURE SURVEY *

BOT AVG=1724.0 DEG F
BOT HOT SPOT: TC# 2 = 1878 DEG F
BOT PATTERN FACTOR = .1288

	TC#	AVERAGE	STD DEV
OUTER ANNULUS	1	1798	13
	4	1716	38
	7	0	255
	10	1533	22
	13	1615	16
CENTER ANNULUS	2	1878	13
	5	1784	13
	8	1796	11
	11	1680	15
	14	1772	10
INNER ANNULUS	3	1857	13
	6	1638	36
	9	1636	29
	12	1631	18
	15	1800	12

* EXHAUST CHEMISTRY *

CO.. .045 % CO2..4.45 % O2..14.8 % UBH.. 8.3 PPM <PROPANE>
NO.. 43.5 PPM NOX.. 51.5 PPM NO2.. 8.0 PPM <NOX-NO>
SMOKE NUMBER: 21.5

COMBUSTION EFFICIENCY, CALCULATED FROM EXHAUST CHEMISTRY: 99.4560
FUEL/AIR RATIO, CALCULATED FROM EXHAUST CHEMISTRY: .021222
REMARKS:

Figure 29 - Test Report of Experiment No. 22

U. S. ARMY FUELS & LUBRICANTS RESEARCH LABORATORY
TURBINE COMBUSTOR FACILITY

*** STUDY OF FUEL EMULSIONS FOR THE REDUCTION OF EXHAUST PARTICULATES *
U.S. NAVY AIR ENGINEERING CENTER

DATE: 6/17/76 TIME: 11: 2
COMBUSTOR SYSTEM: T-63 POWER POINT: 100%
TEST FUEL: JP5-P EMULSIFIED WITH 15% WATER

***** EXPERIMENTAL TEST CONDITIONS *****

	AVERAGE	STD.DEV.	DESIRED	LAST SCAN
INLET AIR PRESSURE, PSIA	67.16	.17	65.40	67.20
INLET AIR TEMPERATURE, DEG F	524.88	1.21	524.00	524.11
AIR FLOW RATE, LBS/SEC	2.318	.012	2.340	2.310
FUEL FLOW RATE, LBS/MIN	3.194	.030	3.250	3.231
FUEL/AIR RATIO	.02297	.00025	.02230	.02331
AIR FLOW LOADING FACTOR	1.0029	.0067	1.0940	1.0782

FUEL PRESSURE= 360
FUEL TEMPERATURE=133.6 DEG F

* BURNER OUTLET TEMPERATURE SURVEY *

BOT AVG=1740.0 DEG F
BOT HOT SPOT: TC# 2 = 1893 DEG F
BOT PATTERN FACTOR = .1256

	TC#	AVERAGE	STD DEV
OUTER ANNULUS	1	1838	15
	4	1655	40
	7	0	30
	10	0	27
	13	1593	27
CENTER ANNULUS	2	1893	15
	5	1800	16
	8	1807	12
	11	1691	13
	14	1789	10
INNER ANNULUS	3	1861	10
	6	1621	40
	9	1635	15
	12	1615	29
	15	1823	10

* EXHAUST CHEMISTRY *

CO.. .044 % CO2..4.55 % O2..14.7 % UBH.5.4 PPM <PROPANE>
NO.. 44.0 PPM NOX.. 52.3 PPM NO2.. 8.3 PPM <NOX-NO>
SMOKE NUMBER: 17.6

COMBUSTION EFFICIENCY, CALCULATED FROM EXHAUST CHEMISTRY: 99.4976
FUEL/AIR RATIO,CALCULATED FROM EXHAUST CHEMISTRY: .021630
REMARKS:

Figure 30 - Test Report of Experiment No. 23

U. S. ARMY FUELS & LUBRICANTS RESEARCH LABORATORY
TURBINE COMBUSTOR FACILITY

*** STUDY OF FUEL EMULSIONS FOR THE REDUCTION OF EXHAUST PARTICULATES -
U.S. NAVY AIR ENGINEERING CENTER

DATE: 6/17/76 TIME: 11:43
COMBUSTOR SYSTEM: T-63 POWER POINT: 100%
TEST FUEL: JP5-P EMULSIFIED WITH 20% WATER

***** EXPERIMENTAL TEST CONDITIONS *****

	AVERAGE	STD.DEV.	DESIRED	LAST SCAN
INLET AIR PRESSURE, PSIA	66.82	.27	65.40	67.80
INLET AIR TEMPERATURE, DEG F	524.52	1.17	524.00	524.97
AIR FLOW RATE, LBS/SEC	2.311	.013	2.340	2.289
FUEL FLOW RATE, LBS/MIN	3.302	.032	3.380	3.305
FUEL/AIR RATIO	.02381	.00024	.12300	.02407
AIR FLOW LOADING FACTOR	1.0854	.0093	1.0940	1.0595

FUEL PRESSURE= 370
FUEL TEMPERATURE=135.3 DEG F

* BURNER OUTLET TEMPERATURE SURVEY *

BOT AVG=1712.3 DEG F
BOT HOT SPOT: TC# 2 = 1833 DEG F
BOT PATTERN FACTOR = .1819

	TC#	AVERAGE	STD DEV
OUTER ANNULUS	1	1792	11
	4	1704	33
	7	0	62
	10	0	60
	13	1569	26
CENTER ANNULUS	2	1833	11
	5	1761	13
	8	1768	12
	11	1637	13
	14	1737	8
INNER ANNULUS	3	1820	14
	6	0	203
	9	1599	13
	12	1558	27
	15	1778	11

* EXHAUST CHEMISTRY *

CO.. .052 % CO2..4.35 % O2..15.0 % UBH.11.4 . PPM <PROPANE
NO.. 33.0 PPM NOX.. 41.5 PPM NO2.. 8.5 PPM <NOX-NO>
SMOKE NUMBER: 14.7

COMBUSTION EFFICIENCY, CALCULATED FROM EXHAUST CHEMISTRY: 99.3520
FUEL/AIR RATIO,CALCULATED FROM EXHAUST CHEMISTRY: .020732
REMARKS:

Figure 31 - Test Report of Experiment No. 24

U. S. ARMY FUELS & LUBRICANTS RESEARCH LABORATORY
TURBINE COMBUSTOR FACILITY

** STUDY OF FUEL EMULSIONS FOR THE REDUCTION OF EXHAUST PARTICULATES **
U.S. NAVY AIR ENGINEERING CENTER

DATE: 6-17-76 TIME: 12:10
COMBUSTOR SYSTEM: T-63 POWER POINT: 100%
TEST FUEL: JP5-P EMULSIFIED WITH 25% ~~METHANOL~~ water

***** EXPERIMENTAL TEST CONDITIONS *****

	AVERAGE	STD.DEV.	DESIRED	LAST SCAN
INLET AIR PRESSURE, PSIA	65.39	.20	65.40	65.20
INLET AIR TEMPERATURE, DEG F	524.05	1.23	524.00	524.11
AIR FLOW RATE, LBS/SEC	2.312	.015	2.340	2.327
FUEL FLOW RATE, LBS/MIN	3.489	.035	3.520	3.449
FUEL/AIR RATIO	.02516	.00030	.02480	.02470
AIR FLOW LOADING FACTOR	1.1091	.0074	1.0940	1.1196

FUEL PRESSURE= 390
FUEL TEMPERATURE=134.5 DEG F

* BURNER OUTLET TEMPERATURE SURVEY *

BOT AVG=1782.3 DEG F
BOT HOT SPOT: TC# 3 = 1831 DEG F
BOT PATTERN FACTOR = .1095

	TC#	AVERAGE	STD DEV
OUTER ANNULUS	1	1786	13
	4	1703	36
	7	0	73
	10	0	22
	13	1589	13
CENTER ANNULUS	2	1829	13
	5	1751	12
	8	1758	12
	11	1642	12
	14	1735	10
INNER ANNULUS	3	1831	15
	6	1582	26
	9	1590	11
	12	1562	29
	15	1765	12

* EXHAUST CHEMISTRY *

CO.. .058 % CO2..4.35 % O2..14.7 % UBH..14.7 PPM <PROPANE>
NO.. 29.5 PPM NOX.. 38.3 PPM NO2.. 8.8 PPM <NOX-NO>
SMOKE NUMBER: 12.2

COMBUSTION EFFICIENCY, CALCULATED FROM EXHAUST CHEMISTRY: 99.2685
FUEL/AIR RATIO,CALCULATED FROM EXHAUST CHEMISTRY: .021053
REMARKS:

Figure 32 - Test Report of Experiment No. 25

U. S. ARMY FUELS & LUBRICANTS RESEARCH LABORATORY
TURBINE COMBUSTOR FACILITY

** STUDY OF FUEL EMULSIONS FOR THE REDUCTION OF EXHAUST PARTICULATES **
U.S. NAVY AIR ENGINEERING CENTER

DATE: 6-18-76 TIME: 9:19
COMBUSTOR SYSTEM: T-63 POWER POINT: 100%
TEST FUEL: JP5-P

***** EXPERIMENTAL TEST CONDITIONS *****

	AVERAGE	STD.DEV.	DESIRED	LAST SCAN
INLET AIR PRESSURE, PSIA	67.04	.24	65.40	67.60
INLET AIR TEMPERATURE, DEG F	526.91	1.07	524.00	526.92
AIR FLOW RATE, LBS/SEC	2.336	.013	2.340	2.335
FUEL FLOW RATE, LBS/MIN	2.754	.023	3.660	2.748
FUEL/AIR RATIO	.01965	.00019	.02570	.01962
AIR FLOW LOADING FACTOR	1.0948	.0081	1.0940	1.0850

FUEL PRESSURE= 320
FUEL TEMPERATURE=133.6 DEG F

* BURNER OUTLET TEMPERATURE SURVEY *

BOT AVG=1714.6 DEG F
BOT HOT SPOT: TC# 2 = 1850 DEG F
BOT PATTERN FACTOR = .1139

	TC#	AVERAGE	STD DEV
OUTER ANNULUS	1	1767	13
	4	1636	85
	7	1553	22
	10	1612	10
	13	1632	10
CENTER ANNULUS	2	1850	13
	5	1753	14
	8	1752	9
	11	1710	14
	14	1771	10
INNER ANNULUS	3	1825	13
	6	0	177
	9	1675	12
	12	1668	15
	15	1800	12

* EXHAUST CHEMISTRY *

CO.. .039 % CO2..4.32 % O2..15.2 % UBH..3.6 PPM <PROPANE>
NO.. 50.3 PPM NOX.. 60.5 PPM NO2..10.2 PPM <NOX-NO>
SMOKE NUMBER: 29.4

COMBUSTION EFFICIENCY, CALCULATED FROM EXHAUST CHEMISTRY: 99.5348
FUEL/AIR RATIO,CALCULATED FROM EXHAUST CHEMISTRY: .020382
REMARKS:

Figure 33 - Test Report of Experiment No. 26

U. S. ARMY FUELS & LUBRICANTS RESEARCH LABORATORY
TURBINE COMBUSTOR FACILITY

** STUDY OF FUEL EMULSIONS FOR THE REDUCTION OF EXHAUST PARTICULATES **
U.S. NAVY AIR ENGINEERING CENTER

DATE: 6/18/76 TIME: 9:38
COMBUSTOR SYSTEM: T-63 POWER POINT: 100%
TEST FUEL: JP5-P EMULSIFIED WITH 5% WATER

***** EXPERIMENTAL TEST CONDITIONS *****

	AVERAGE	STD.DEV.	DESIRED	LAST SCAN
INLET AIR PRESSURE, PSIA	66.95	.13	1.09	67.00
INLET AIR TEMPERATURE, DEG F	526.48	.92	50.30	527.13
AIR FLOW RATE, LBS/SEC	2.331	.014	10.200	2.323
FUEL FLOW RATE, LBS/MIN	2.947	.025	10.700	2.934
FUEL/AIR RATIO	.02107	.00022	.03900	.02105
AIR FLOW LOADING FACTOR	1.0935	.0072	4.3200	1.0892

FUEL PRESSURE= 340
FUEL TEMPERATURE=134.9 DEG F

* BURNER OUTLET TEMPERATURE SURVEY *

BOT AVG=1724.8 DEG F
BOT HOT SPOT: TC# 2 = 1841 DEG F
BOT PATTERN FACTOR = .0971

	TC#	AVERAGE	STD DEV
OUTER ANNULUS	1	1768	14
	4	0	60
	7	1538	45
	10	1590	9
	13	1631	10
CENTER ANNULUS	2	1841	14
	5	1708	12
	8	1704	11
	11	1721	12
	14	1760	9
INNER ANNULUS	3	1835	13
	6	0	37
	9	1681	10
	12	1676	25
	15	1793	10

* EXHAUST CHEMISTRY *

CO.. .046 % CO2..4.40 % O2..14.8 % UBH.. 6.3 PPM (PROPANE
NO.. 46.3 PPM NOX.. 55.0 PPM NO2.. 8.7 PPM (NOX-NO
SMOKE NUMBER: 22.3

COMBUSTION EFFICIENCY, CALCULATED FROM EXHAUST CHEMISTRY: 99.4528
FUEL/AIR RATIO,CALCULATED FROM EXHAUST CHEMISTRY: .021060
REMARKS:

Figure 34 - Test Report of Experiment No. 27

U. S. ARMY FUELS & LUBRICANTS RESEARCH LABORATORY
TURBINE COMBUSTOR FACILITY

** STUDY OF FUEL EMULSIONS FOR THE REDUCTION OF EXHAUST PARTICULATES **
U.S. NAVY AIR ENGINEERING CENTER

DATE: 6/18/76 TIME: 10: 8
COMBUSTOR SYSTEM: T-63 POWER POINT: 100%
TEST FUEL: JP5-P EMULSIFIED WITH 30% WATER

***** EXPERIMENTAL TEST CONDITIONS *****

	AVERAGE	STD.DEV.	DESIRED	LAST SCAN
INLET AIR PRESSURE, PSIA	67.07	.31	65.40	66.80
INLET AIR TEMPERATURE, DEG F	527.65	1.32	524.00	526.48
AIR FLOW RATE, LBS/SEC	2.330	.012	2.340	2.322
FUEL FLOW RATE, LBS/MIN	3.615	.027	3.610	3.662
FUEL/AIR RATIO	.02586	.00022	.02570	.02628
AIR FLOW LOADING FACTOR	1.0919	.0060	1.0940	1.0918

FUEL PRESSURE= 415
FUEL TEMPERATURE=125.0 DEG F

* BURNER OUTLET TEMPERATURE SURVEY *

BOT AVG=1710.4 DEG F
BOT HOT SPOT: TC# 2 = 1804 DEG F
BOT PATTERN FACTOR = .0792

	TC#	AVERAGE	STD DEV
OUTER ANNULUS	1	1741	11
	4	1705	26
	7	0	40
	10	1596	12
	13	1610	11
CENTER ANNULUS	2	1804	11
	5	1731	12
	8	1713	11
	11	1719	13
	14	1730	11
INNER ANNULUS	3	1791	13
	6	0	30
	9	1665	12
	12	1681	14
	15	1751	11

* EXHAUST CHEMISTRY *

CO.. .063 % CO2..4.30 % O2..15.0 % UBH.. 30.8 PPM (PROPANE)
NO.. 26.3 PPM NOX.. 34.4 PPM NO2.. 8.1 PPM (NOX-NO)
SMOKE NUMBER: 12.9

COMBUSTION EFFICIENCY, CALCULATED FROM EXHAUST CHEMISTRY: 99.1670
FUEL/AIR RATIO,CALCULATED FROM EXHAUST CHEMISTRY: [illegible]
REMARKS:

Figure 35 - Test Report of Experiment No. 28

U. S. ARMY FUELS & LUBRICANTS RESEARCH LABORATORY
TURBINE COMBUSTOR FACILITY

*** STUDY OF FUEL EMULSIONS FOR THE REDUCTION OF EXHAUST PARTICULATES *
U.S. NAVY AIR ENGINEERING CENTER

DATE: 6/10/76 TIME: 10:39
COMBUSTOR SYSTEM: T-63 POWER POINT: 100%
TEST FUEL: JP5-P EMULSIFIED WITH 40% WATER

***** EXPERIMENTAL TEST CONDITIONS *****

	AVERAGE	STD.DEV.	DESIRED	LAST SCAN
INLET AIR PRESSURE, PSIA	66.12	.18	65.40	66.40
INLET AIR TEMPERATURE, DEG F	527.66	1.23	524.00	525.84
AIR FLOW RATE, LBS/SEC	2.325	.013	2.340	2.344
FUEL FLOW RATE, LBS/MIN	3.895	.029	3.890	3.930
FUEL/AIR RATIO	.02792	.00027	.02770	.02794
AIR FLOW LOADING FACTOR	1.1053	.0066	1.0940	1.1085

FUEL PRESSURE= 445
FUEL TEMPERATURE=122.8 DEG F

* BURNER OUTLET TEMPERATURE SURVEY *

BOT AVG=1684.0 DEG F
BOT HOT SPOT: TC# 3 = 1770 DEG F
BOT PATTERN FACTOR = .0742

	TC#	AVERAGE	STD DEV
OUTER ANNULUS	1	1721	13
	4	1649	53
	7	0	38
	10	1585	13
	13	1562	16
CENTER ANNULUS	2	1769	13
	5	1722	14
	8	1702	13
	11	1694	13
	14	1709	12
INNER ANNULUS	3	1770	15
	6	0	60
	9	1630	19
	12	1647	17
	15	1732	14

* EXHAUST CHEMISTRY *

CO.. .073 % CO2..4.33 % O2..15.0 % UBH.. 30.7 PPM <PROPANE>
NO.. 20.5 PPM NOX.. 29.5 PPM NO2.. 9.0 PPM <NOX-NO>
SMOKE NUMBER: 10.2

COMBUSTION EFFICIENCY, CALCULATED FROM EXHAUST CHEMISTRY: 99.0028
FUEL AIR RATIO,CALCULATED FROM EXHAUST CHEMISTRY: .020773
REMARKS:

Figure 36 - Test Report of Experiment No. 29

U. S. ARMY FUELS & LUBRICANTS RESEARCH LABORATORY
TURBINE COMBUSTOR FACILITY

*** STUDY OF FUEL EMULSIONS FOR THE REDUCTION OF EXHAUST PARTICULATES --
U.S. NAVY AIR ENGINEERING CENTER

DATE: 6/18/76 TIME: 12:15
COMBUSTOR SYSTEM: T-63 POWER POINT: 25%
TEST FUEL: JP5-P

***** EXPERIMENTAL TEST CONDITIONS *****

	AVERAGE	STD.DEV.	DESIRED	LAST SCAN
INLET AIR PRESSURE, PSIA	45.37	.41	45.10	45.30
INLET AIR TEMPERATURE, DEG F	352.56	.66	353.00	352.50
AIR FLOW RATE, LBS/SEC	1.806	.011	1.810	1.796
FUEL FLOW RATE, LBS/MIN	1.311	.013	1.310	1.324
FUEL/AIR RATIO	.01210	.00014	.01210	.01228
AIR FLOW LOADING FACTOR	1.1345	.0134	1.1450	1.1300

FUEL PRESSURE= 100
FUEL TEMPERATURE=157.4 DEG F

* BURNER OUTLET TEMPERATURE SURVEY *

BOT AVG=1133.1 DEG F
BOT HOT SPOT: TC# 2 = 1256 DEG F
BOT PATTERN FACTOR = .1569

	TC#	AVERAGE	STD DEV
OUTER ANNULUS	1	1179	10
	4	1127	28
	7	0	25
	10	0	6
	13	1026	7
CENTER ANNULUS	2	1256	10
	5	1135	12
	8	1158	8
	11	1041	8
	14	1124	7
INNER ANNULUS	3	1236	11
	6	0	43
	9	1102	8
	12	1036	12
	15	1177	10

* EXHAUST CHEMISTRY *

CO.. .096 % CO2..2.54 % O2..17.5 % UBH. 140.0 PPM <PROPANE>
NO.. 11.7 PPM NOX.. 19.3 PPM NO2.. 7.6 PPM <NOX-NO>
SMOKE NUMBER: 14.6

COMBUSTION EFFICIENCY, CALCULATED FROM EXHAUST CHEMISTRY: 96.7323
FUEL/AIR RATIO,CALCULATED FROM EXHAUST CHEMISTRY: .012686
REMARKS:

Figure 37 - Test Report of Experiment No. 30

U. S. ARMY FUELS & LUBRICANTS RESEARCH LABORATORY
TURBINE COMBUSTOR FACILITY

*** STUDY OF FUEL EMULSIONS FOR THE REDUCTION OF EXHAUST PARTICULATES ***
U.S. NAVY AIR ENGINEERING CENTER

DATE: 5/18/76 TIME: 12:43
COMBUSTOR SYSTEM: T-63 POWER POINT: 25%
TEST FUEL: JP5-P EMULSIFIED WITH 10% WATER

***** EXPERIMENTAL TEST CONDITIONS *****

	AVERAGE	STD.DEV.	DESIRED	LAST SCAN
INLET AIR PRESSURE, PSIA	44.84	.18	45.10	44.70
INLET AIR TEMPERATURE, DEG F	351.75	.61	353.00	352.50
AIR FLOW RATE, LBS/SEC	1.810	.010	1.810	1.804
FUEL FLOW RATE, LBS/MIN	1.418	.019	1.440	1.413
FUEL/AIR RATIO	.01306	.00019	.01330	.01305
AIR FLOW LOADING FACTOR	1.1498	.0000	1.1450	1.1505

FUEL PRESSURE= 192
FUEL TEMPERATURE=152.6 DEG F

* BURNER OUTLET TEMPERATURE SURVEY *

BOT AVG=1127.5 DEG F
BOT HOT SPOT: TC# 3 = 1254 DEG F
BOT PATTERN FACTOR = .1626

	TC#	AVERAGE	STD DEV
OUTER ANNULUS	1	1166	18
	4	1162	10
	7	1035	6
	10	0	11
	13	1034	8
CENTER ANNULUS	2	1246	14
	5	1144	12
	8	1148	11
	11	1036	9
	14	1122	10
INNER ANNULUS	3	1254	12
	6	1131	8
	9	1102	10
	12	1039	9
	15	1160	12

* EXHAUST CHEMISTRY *

CO.. .122 % CO2..2.50 % O2..17.3 % UBH. 253.3 PPM (PROPANE)
NO.. 12.3 PPM NOX.. 17.0 PPM NO2.. 4.7 PPM (NOX-NO)
SMOKE NUMBER: 8.6

COMBUSTION EFFICIENCY, CALCULATED FROM EXHAUST CHEMISTRY: 95.0419
FUEL/AIR RATIO,CALCULATED FROM EXHAUST CHEMISTRY: .012923
REMARKS:

Figure 38 - Test Report of Experiment No. 31

U. S. ARMY FUELS & LUBRICANTS RESEARCH LABORATORY
TURBINE COMBUSTOR FACILITY

*** STUDY OF FUEL EMULSIONS FOR THE REDUCTION OF EXHAUST PARTICULATES ***
U.S. NAVY AIR ENGINEERING CENTER

DATE: 5/19/76 TIME: 1: 3
COMBUSTOR SYSTEM: T-63 POWER POINT: 25%
TEST FUEL: JP5-P EMULSIFIED WITH 20% WATER

***** EXPERIMENTAL TEST CONDITIONS *****

	AVERAGE	STD.DEV.	DESIRED	LAST SCAN
INLET AIR PRESSURE, PSIA	44.57	.18	45.10	44.60
INLET AIR TEMPERATURE, DEG F	351.81	.49	353.00	352.07
AIR FLOW RATE, LBS/SEC	1.805	.010	1.810	1.805
FUEL FLOW RATE, LBS/MIN	1.564	.012	1.570	1.567
FUEL/AIR RATIO	.01444	.00014	.01450	.01447
AIR FLOW LOADING FACTOR	1.1536	.0081	1.1450	1.1532

FUEL PRESSURE= 200
FUEL TEMPERATURE=148.3 DEG F

* BURNER OUTLET TEMPERATURE SURVEY *

BOT AVG=1113.9 DEG F
BOT HOT SPOT: TC# 3 = 1239 DEG F
BOT PATTERN FACTOR = .1645

	TC#	AVERAGE	STD DEV
OUTER ANNULUS	1	1138	11
	4	1150	11
	7	1060	9
	10	0	14
	13	1007	7
CENTER ANNULUS	2	1224	11
	5	1139	9
	8	1136	13
	11	1016	9
	14	1095	8
INNER ANNULUS	3	1239	12
	6	1127	7
	9	1100	8
	12	1021	7
	15	1142	10

* EXHAUST CHEMISTRY *

CO.. .135 % CO2..2.50 % O2..17.3 % UBH. 327.7 PPM (PROPANE)
NO.. 10.7 PPM NOX.. 13.7 PPM NO2.. 3.6 PPM (NOX-NO)
SMOKE NUMBER: 5.6

COMBUSTION EFFICIENCY, CALCULATED FROM EXHAUST CHEMISTRY: 94.0660
FUEL/AIR RATIO,CALCULATED FROM EXHAUST CHEMISTRY: .013004
REMARKS:

Figure 39 - Test Report of Experiment No. 32

U. S. ARMY FUELS & LUBRICANTS RESEARCH LABORATORY
TURBINE COMBUSTOR FACILITY

*** STUDY OF FUEL EMULSIONS FOR THE REDUCTION OF EXHAUST PARTICULATES *
U.S. NAVY AIR ENGINEERING CENTER

DATE: 6/18/76 TIME: 1:23
COMBUSTOR SYSTEM: T-63 POWER POINT: 25%
TEST FUEL: JP5-P EMULSIFIED WITH 30% WATER

***** EXPERIMENTAL TEST CONDITIONS *****

	AVERAGE	STD.DEV.	DESIRED	LAST SCAN
INLET AIR PRESSURE, PSIA	44.98	.17	45.10	44.80
INLET AIR TEMPERATURE, DEG F	352.66	.66	353.00	352.07
AIR FLOW RATE, LBS/SEC	1.801	.011	1.810	1.789
FUEL FLOW RATE, LBS/MIN	1.666	.015	1.708	1.658
FUEL/AIR RATIO	.01542	.00018	.01578	.01544
AIR FLOW LOADING FACTOR	1.1432	.0088	1.1450	1.1383

FUEL PRESSURE= 205
FUEL TEMPERATURE=141.0 DEG F

* BURNER OUTLET TEMPERATURE SURVEY *

BOT AVG=1079.5 DEG F
BOT HOT SPOT: TC# 3 = 1217 DEG F
BOT PATTERN FACTOR = .1895

	TC#	AVERAGE	STD DEV
OUTER ANNULUS	1	1093	12
	4	1143	11
	7	1028	7
	10	995	7
	13	985	6
CENTER ANNULUS	2	1186	12
	5	1110	11
	8	1091	10
	11	998	8
	14	1066	7
INNER ANNULUS	3	1217	11
	6	1097	9
	9	1082	9
	12	997	8
	15	1105	9

* EXHAUST CHEMISTRY *

CO.. .142 % CO2..2.40 % O2..17.4 % UBH. 393.7 PPM (PROPANE)
NO.. 8.6 PPM NOX.. 11.3 PPM NO2.. 2.5 PPM (NOX-NO)
SMOKE NUMBER: 4.8

COMBUSTION EFFICIENCY, CALCULATED FROM EXHAUST CHEMISTRY: 93.0364
FUEL/AIR RATIO,CALCULATED FROM EXHAUST CHEMISTRY: .012759
REMARKS:

Figure 40 - Test Report of Experiment No. 33

U. S. ARMY FUELS & LUBRICANTS RESEARCH LABORATORY
TURBINE COMBUSTOR FACILITY

*** STUDY OF FUEL EMULSIONS FOR THE REDUCTION OF EXHAUST PARTICULATES ---
U.S. NAVY AIR ENGINEERING CENTER

DATE: 6 18 76 TIME: 1:46
COMBUSTOR SYSTEM: T-63 POWER POINT: 25%
TEST FUEL: JP5-P EMULSIFIED WITH 40% WATER

***** EXPERIMENTAL TEST CONDITIONS *****

	AVERAGE	STD.DEV.	DESIRED	LAST SCAN
INLET AIR PRESSURE, PSIA	44.87	.13	45.10	44.80
INLET AIR TEMPERATURE, DEG F	352.60	.62	353.00	352.50
AIR FLOW RATE, LBS/SEC	1.795	.011	1.810	1.792
FUEL FLOW RATE, LBS/MIN	1.797	.014	1.830	1.794
FUEL/AIR RATIO	.01668	.00017	.01690	.01669
AIR FLOW LOADING FACTOR	1.1406	.0075	1.1450	1.1399

FUEL PRESSURE= 213
FUEL TEMPERATURE=139.2 DEG F

* BURNER OUTLET TEMPERATURE SURVEY *

BOT AVG=1090.4 DEG F
BOT HOT SPOT: TC# 3 = 1217 DEG F
BOT PATTERN FACTOR = .1720

	TC#	AVERAGE	STD DEV
OUTER ANNULUS	1	1081	12
	4	1150	10
	7	1024	5
	10	1012	6
	13	0	5
CENTER ANNULUS	2	1173	12
	5	1100	9
	8	1082	9
	11	1004	8
	14	1063	6
INNER ANNULUS	3	1217	12
	6	1086	6
	9	1084	8
	12	0	6
	15	1100	8

* EXHAUST CHEMISTRY *

CO.. .152 % CO2..2.40 % O2..17.5 % UBH. 468.0 PPM (PROPANE)
NO.. 8.0 PPM NOX.. 9.7 PPM NO2.. 1.7 PPM (NOX-NO)
SMOKE NUMBER: 3.3

COMBUSTION EFFICIENCY, CALCULATED FROM EXHAUST CHEMISTRY: 92.1171
FUEL/AIR RATIO,CALCULATED FROM EXHAUST CHEMISTRY: .012847
REMARKS:

Figure 41 - Test Report of Experiment No. 34

U. S. ARMY FUELS & LUBRICANTS RESEARCH LABORATORY
TURBINE COMBUSTOR FACILITY

*** STUDY OF FUEL EMULSIONS FOR THE REDUCTION OF EXHAUST PARTICULATES **
U.S. NAVY AIR ENGINEERING CENTER

DATE: 6/21/76 TIME: 10: 8
COMBUSTOR SYSTEM: T-63 POWER POINT: 100%
TEST FUEL: JP5-P

***** EXPERIMENTAL TEST CONDITIONS *****

	AVERAGE	STD.DEV.	DESIRED	LAST SCAN
INLET AIR PRESSURE, PSIA	68.49	.19	65.40	68.50
INLET AIR TEMPERATURE, DEG F	525.12	3.90	524.00	525.84
AIR FLOW RATE, LBS/SEC	2.375	.014	2.340	2.388
FUEL FLOW RATE, LBS/MIN	2.839	.027	2.826	2.831
FUEL/AIR RATIO	.01992	.00023	.01980	.01975
AIR FLOW LOADING FACTOR	1.0883	.0065	1.0940	1.0940

FUEL PRESSURE= 318
FUEL TEMPERATURE=126.7 DEG F

* BURNER OUTLET TEMPERATURE SURVEY *

BOT AVG=1719.1 DEG F
BOT HOT SPOT: TC# 2 = 1850 DEG F
BOT PATTERN FACTOR = .1095

	TC#	AVERAGE	STD DEV
OUTER ANNULUS	1	1753	13
	4	1719	28
	7	1680	23
	10	1559	10
	13	1592	12
CENTER ANNULUS	2	1850	13
	5	1773	17
	8	1792	14
	11	1679	14
	14	1730	10
INNER ANNULUS	3	1846	14
	6	1676	34
	9	1705	13
	12	1652	12
	15	1700	12

* EXHAUST CHEMISTRY *

CO.. .036 % CO2..4.35 % O2..15.1 % UBH..3.5 PPM (PROPANE)
NO.. 56.0 PPM NOX.. 61.7 PPM NO2.. 5.7 PPM (NOX-NO)
SMOKE NUMBER: 20.5

COMBUSTION EFFICIENCY, CALCULATED FROM EXHAUST CHEMISTRY: 99.5485
FUEL/AIR RATIO,CALCULATED FROM EXHAUST CHEMISTRY: .020564
REMARKS:

Figure 42 - Test Report of Experiment No. 35

U. S. ARMY FUELS & LUBRICANTS RESEARCH LABORATORY
TURBINE COMBUSTOR FACILITY

*** STUDY OF FUEL EMULSIONS FOR THE REDUCTION OF EXHAUST PARTICULATES **
U.S. NAVY AIR ENGINEERING CENTER

DATE: 6/21/76 TIME: 10:34
COMBUSTOR SYSTEM: T-63 POWER POINT: 100%
TEST FUEL: JP5-P EMULSIFIED WITH 40% WATER

***** EXPERIMENTAL TEST CONDITIONS *****

	AVERAGE	STD.DEV.	DESIRED	LAST SCAN
INLET AIR PRESSURE, PSIA	67.82	.26	65.40	68.30
INLET AIR TEMPERATURE, DEG F	526.71	2.83	524.00	531.45
AIR FLOW RATE, LBS/SEC	2.367	.018	2.340	2.346
FUEL FLOW RATE, LBS/MIN	3.971	.023	3.970	4.018
FUEL/AIR RATIO	.02796	.00027	.02770	.02854
AIR FLOW LOADING FACTOR	1.0962	.0071	1.0940	1.0817

FUEL PRESSURE= 435
FUEL TEMPERATURE=118.1 DEG F

* BURNER OUTLET TEMPERATURE SURVEY *

BOT AVG=1678.4 DEG F
BOT HOT SPOT: TC# 2 = 1796 DEG F
BOT PATTERN FACTOR = .1023

	TC#	AVERAGE	STD DEV
OUTER ANNULUS	1	1717	10
	4	1666	29
	7	1649	10
	10	1536	10
	13	1582	9
CENTER ANNULUS	2	1796	10
	5	1753	12
	8	1725	12
	11	1693	13
	14	1703	9
INNER ANNULUS	3	1763	15
	6	1534	141
	9	1668	10
	12	1651	11
	15	1739	10

* EXHAUST CHEMISTRY *

CO.. .070 % CO2..4.40 % O2..14.7 % UBH..25.5 PPM (PROPANE)
NO.. 25.0 PPM NOX.. 31.0 PPM NO2.. 6.0 PPM (NOX-NO)
SMOKE NUMBER: 9.5

COMBUSTION EFFICIENCY, CALCULATED FROM EXHAUST CHEMISTRY: 99.0824
FUEL/AIR RATIO,CALCULATED FROM EXHAUST CHEMISTRY: .021278
REMARKS:

Figure 43 - Test Report of Experiment No. 36

U. S. ARMY FUELS & LUBRICANTS RESEARCH LABORATORY
TURBINE COMBUSTOR FACILITY

*** STUDY OF FUEL EMULSIONS FOR THE REDUCTION OF EXHAUST PARTICULATES **
U.S. NAVY AIR ENGINEERING CENTER

DATE: 6/21/76 TIME: 10:53
COMBUSTOR SYSTEM: T-63 POWER POINT: 100%
TEST FUEL: JP5-P EMULSIFIED WITH 50% WATER

***** EXPERIMENTAL TEST CONDITIONS *****

	AVERAGE	STD.DEV.	DESIRED	LAST SCAN
INLET AIR PRESSURE, PSIA	68.39	.17	65.40	68.68
INLET AIR TEMPERATURE, DEG F	526.14	2.71	524.00	527.35
AIR FLOW RATE, LBS/SEC	2.358	.021	2.340	2.373
FUEL FLOW RATE, LBS/MIN	4.239	.027	4.260	4.246
FUEL/AIR RATIO	.02997	.00033	.02970	.02981
AIR FLOW LOADING FACTOR	1.0826	.0095	1.0940	1.0871

FUEL PRESSURE= 470
FUEL TEMPERATURE=114.6 DEG F

* BURNER OUTLET TEMPERATURE SURVEY *

BOT AVG=1668.4 DEG F
BOT HOT SPOT: TC# 2 = 1763 DEG F
BOT PATTERN FACTOR = .0829

	TC#	AVERAGE	STD DEV
OUTER ANNULUS	1	1699	9
	4	1708	28
	7	1562	31
	10	1532	9
	13	1580	9
CENTER ANNULUS	2	1763	9
	5	1740	14
	8	1709	11
	11	1682	11
	14	1689	9
INNER ANNULUS	3	1747	12
	6	1631	29
	9	1648	9
	12	1611	19
	15	1724	12

* EXHAUST CHEMISTRY *

CO.. .080 % CO2..4.40 % O2..14.7 % UBH.. 38.9 PPM <PROPANE>
NO.. 20.5 PPM NOX.. 26.4 PPM NO2.. 5.9 PPM <NOX-NO>
SMOKE NUMBER: 8.2

COMBUSTION EFFICIENCY, CALCULATED FROM EXHAUST CHEMISTRY: 98.8921
FUEL/AIR RATIO,CALCULATED FROM EXHAUST CHEMISTRY: .021335
REMARKS:

Figure 44 - Test Report of Experiment No. 37

U. S. ARMY FUELS & LUBRICANTS RESEARCH LABORATORY
TURBINE COMBUSTOR FACILITY

*** STUDY OF FUEL EMULSIONS FOR THE REDUCTION OF EXHAUST PARTICULATES **
U.S. NAVY AIR ENGINEERING CENTER

DATE: 6/21/76 TIME: 2:25
COMBUSTOR SYSTEM: T-63 POWER POINT: 100%
TEST FUEL: JP5-NBR

***** EXPERIMENTAL TEST CONDITIONS *****

	AVERAGE	STD.DEV.	DESIRED	LAST SCAN
INLET AIR PRESSURE, PSIA	66.16	.12	65.40	66.10
INLET AIR TEMPERATURE, DEG F	527.47	3.43	524.00	523.68
AIR FLOW RATE, LBS/SEC	2.310	.017	2.280	2.302
FUEL FLOW RATE, LBS/MIN	2.716	.025	2.708	2.709
FUEL/AIR RATIO	.01960	.00022	.01980	.01961
AIR FLOW LOADING FACTOR	1.0970	.0078	1.0940	1.0923

FUEL PRESSURE= 300
FUEL TEMPERATURE=137.1 DEG F

* BURNER OUTLET TEMPERATURE SURVEY *

BOT AVG=1682.8 DEG F
BOT HOT SPOT: TC# 8 = 1790 DEG F
BOT PATTERN FACTOR = .0932

	TC#	AVERAGE	STD DEV
OUTER ANNULUS	1	1678	12
	4	1675	39
	7	1614	45
	10	1564	19
	13	1579	9
CENTER ANNULUS	2	1786	12
	5	1743	13
	8	1790	14
	11	1662	14
	14	1692	11
INNER ANNULUS	3	1772	15
	6	1630	103
	9	1696	11
	12	1634	13
	15	1728	11

* EXHAUST CHEMISTRY *

CO.. .040 % CO2..4.15 % O2..15.2 % UBH..4.3 PPM <PROPANE>
NO.. 49.8 PPM NOX.. 55.5 PPM NO2.. 5.7 PPM <NOX-NO>
SMOKE NUMBER: 26.6

COMBUSTION EFFICIENCY, CALCULATED FROM EXHAUST CHEMISTRY: 99.5018
FUEL/AIR RATIO,CALCULATED FROM EXHAUST CHEMISTRY: .019809
REMARKS:

Figure 45 - Test Report of Experiment No. 38

U. S. ARMY FUELS & LUBRICANTS RESEARCH LABORATORY
TURBINE COMBUSTOR FACILITY

*** STUDY OF FUEL EMULSIONS FOR THE REDUCTION OF EXHAUST PARTICULATES ***
U.S. NAVY AIR ENGINEERING CENTER

DATE: 6/21/76 TIME: 2:51
COMBUSTOR SYSTEM: T-63 POWER POINT: 100%
TEST FUEL: JP5-HBR EMULSIFIED WITH 15% WATER

***** EXPERIMENTAL TEST CONDITIONS *****

	AVERAGE	STD.DEV.	DESIRED	LAST SCAN
INLET AIR PRESSURE, PSIA	65.56	.24	65.40	65.60
INLET AIR TEMPERATURE, DEG F	527.36	2.89	524.00	526.05
AIR FLOW RATE, LBS/SEC	2.305	.019	2.280	2.315
FUEL FLOW RATE, LBS/MIN	3.165	.026	3.150	3.190
FUEL/AIR RATIO	.02289	.00026	.02280	.02296
AIR FLOW LOADING FACTOR	1.1047	.0089	1.0940	1.1084

FUEL PRESSURE= 343
FUEL TEMPERATURE=130.6 DEG F

* BURNER OUTLET TEMPERATURE SURVEY *

BOT AVG=1685.5 DEG F
BOT HOT SPOT: TC# 8 = 1777 DEG F
BOT PATTERN FACTOR = .0794

	TC#	AVERAGE	STD DEV
OUTER ANNULUS	1	1678	11
	4	0	103
	7	0	75
	10	1613	12
	13	1577	11
CENTER ANNULUS	2	1769	11
	5	1749	12
	8	1777	14
	11	1697	14
	14	1691	10
INNER ANNULUS	3	1718	12
	6	1614	32
	9	1663	14
	12	1639	12
	15	1727	12

* EXHAUST CHEMISTRY *

CO.. .056 % CO2..4.20 % O2..14.9 % UBH..14.2 PPM (PROPANE)
NO.. 35.8 PPM NOX.. 41.5 PPM NO2.. 5.7 PPM (NOX-NO)
SMOKE NUMBER: 13.2

COMBUSTION EFFICIENCY, CALCULATED FROM EXHAUST CHEMISTRY: 98.2684
FUEL/AIR RATIO, CALCULATED FROM EXHAUST CHEMISTRY: .020336
REMARKS:

Figure 46 - Test Report of Experiment No. 39

U. S. ARMY FUELS & LUBRICANTS RESEARCH LABORATORY
TURBINE COMBUSTOR FACILITY

*** STUDY OF FUEL EMULSIONS FOR THE REDUCTION OF EXHAUST PARTICULATES ***
U.S. NAVY AIR ENGINEERING CENTER

DATE: 6/21/76 TIME: 3:15
COMBUSTOR SYSTEM: T-63 POWER POINT: 100%
TEST FUEL: JP5-HBR EMULSIFIED WITH 30% WATER

***** EXPERIMENTAL TEST CONDITIONS *****

	AVERAGE	STD.DEV.	DESIRED	LAST SCAN
INLET AIR PRESSURE, PSIA	65.91	.25	65.40	66.10
INLET AIR TEMPERATURE, DEG F	527.61	3.18	524.00	525.41
AIR FLOW RATE, LBS/SEC	2.304	.017	2.280	2.315
FUEL FLOW RATE, LBS/MIN	3.522	.030	3.560	3.523
FUEL/AIR RATIO	.02549	.00031	.02570	.02536
AIR FLOW LOADING FACTOR	1.0984	.0097	1.0940	1.0992

FUEL PRESSURE= 378
FUEL TEMPERATURE=123.3 DEG F

* BURNER OUTLET TEMPERATURE SURVEY *

BOT AVG=1650.9 DEG F
BOT HOT SPOT: TC# 8 = 1726 DEG F
BOT PATTERN FACTOR = .0672

	TC#	AVERAGE	STD DEV
OUTER ANNULUS	1	1639	12
	4	0	132
	7	0	135
	10	1575	11
	13	1542	10
CENTER ANNULUS	2	1724	12
	5	1711	12
	8	1726	10
	11	1664	13
	14	1656	10
INNER ANNULUS	3	1657	14
	6	0	113
	9	1630	10
	12	1602	16
	15	1684	8

* EXHAUST CHEMISTRY *

CO.. .069 % CO2..4.15 % O2..14.9 % UBH..28.6 PPM (PROPANE)
NO.. 26.0 PPM NOX.. 33.0 PPM NO2.. 7.0 PPM (NOX-NO)
SMOKE NUMBER: 9.3

COMBUSTION EFFICIENCY, CALCULATED FROM EXHAUST CHEMISTRY: 99.0190
FUEL/AIR RATIO, CALCULATED FROM EXHAUST CHEMISTRY: .020230
REMARKS:

Figure 47 - Test Report of Experiment No. 40

U. S. ARMY FUELS & LUBRICANTS RESEARCH LABORATORY
TURBINE COMBUSTOR FACILITY

*** STUDY OF FUEL EMULSIONS FOR THE REDUCTION OF EXHAUST PARTICULATES
U.S. NAVY AIR ENGINEERING CENTER

DATE: 6-21-76 TIME: 3:51
COMBUSTOR SYSTEM: T-63 POWER POINT: 75%
TEST FUEL: JP5-HBR

***** EXPERIMENTAL TEST CONDITIONS *****

	AVERAGE	STD.DEV.	DESIRED	LAST SCAN
INLET AIR PRESSURE, PSIA	58.24	.65	57.40	57.40
INLET AIR TEMPERATURE, DEG F	473.84	3.65	472.00	477.27
AIR FLOW RATE, LBS/SEC	2.098	.018	2.110	2.061
FUEL FLOW RATE, LBS/MIN	2.103	.031	2.100	2.098
FUEL/AIR RATIO	.01670	.00032	.01660	.01697
AIR FLOW LOADING FACTOR	1.1013	.0159	1.1230	1.0994

FUEL PRESSURE= 240
FUEL TEMPERATURE=154.8 DEG F

* BURNER OUTLET TEMPERATURE SURVEY *

BOT AVG=1483.2 DEG F
BOT HOT SPOT: TC# 2 = 1602 DEG F
BOT PATTERN FACTOR = .1174

	TC#	AVERAGE	STD DEV
OUTER ANNULUS	1	1510	15
	4	1474	23
	7	0	98
	10	1326	22
	13	1367	17
CENTER ANNULUS	2	1602	15
	5	1511	12
	8	1565	14
	11	1438	15
	14	1504	11
INNER ANNULUS	3	1596	14
	6	1450	37
	9	1462	14
	12	1423	16
	15	1538	12

* EXHAUST CHEMISTRY *

CO.. .067 % CO2..3.50 % O2..15.9 % UBH. 34.7 PPM <PROPANE
NO.. 29.4 PPM NOX.. 39.0 PPM NO2.. 9.6 PPM <NOX-NO>
SMOKE NUMBER: 24.3

COMBUSTION EFFICIENCY, CALCULATED FROM EXHAUST CHEMISTRY: 98.8143
FUEL/AIR RATIO,CALCULATED FROM EXHAUST CHEMISTRY: .017095
REMARKS:

Figure 48 - Test Report of Experiment No. 41

U. S. ARMY FUELS & LUBRICANTS RESEARCH LABORATORY
TURBINE COMBUSTOR FACILITY

*** STUDY OF FUEL EMULSIONS FOR THE REDUCTION OF EXHAUST PARTICULATES ***
U.S. NAVY AIR ENGINEERING CENTER

DATE: 6-21-76 TIME: 4:13
COMBUSTOR SYSTEM: T-63 POWER POINT: 75%
TEST FUEL: JP5-HBR EMULSIFIED WITH 15% WATER

***** EXPERIMENTAL TEST CONDITIONS *****

	AVERAGE	STD.DEV.	DESIRED	LAST SCAN
INLET AIR PRESSURE, PSIA	56.84	.27	57.40	56.80
INLET AIR TEMPERATURE, DEG F	474.82	3.30	472.00	473.38
AIR FLOW RATE, LBS/SEC	2.098	.018	2.118	2.095
FUEL FLOW RATE, LBS/MIN	2.422	.031	2.410	2.398
FUEL/AIR RATIO	.01924	.00033	.01910	.01907
AIR FLOW LOADING FACTOR	1.1285	.0095	1.1230	1.1270

FUEL PRESSURE= 263
FUEL TEMPERATURE=141.8 DEG F

* BURNER OUTLET TEMPERATURE SURVEY *

BOT AVG=1432.7 DEG F
BOT HOT SPOT: TC# 2 = 1574 DEG F
BOT PATTERN FACTOR = .1472

	TC#	AVERAGE	STD DEV
OUTER ANNULUS	1	1502	16
	4	1254	79
	7	0	59
	10	1335	11
	13	1376	12
CENTER ANNULUS	2	1574	16
	5	1483	16
	8	1529	16
	11	1435	17
	14	1485	15
INNER ANNULUS	3	1487	17
	6	1316	99
	9	1374	19
	12	1393	19
	15	1516	14

* EXHAUST CHEMISTRY *

CO.. .099 % CO2..3.40 % O2..16.0 % UBH. 89.0 PPM <PROPANE>
NO.. 23.0 PPM NOX.. 29.3 PPM NO2.. 6.3 PPM <NOX-NO>
SMOKE NUMBER: 12.3

COMBUSTION EFFICIENCY, CALCULATED FROM EXHAUST CHEMISTRY: 97.9108
FUEL/AIR RATIO,CALCULATED FROM EXHAUST CHEMISTRY: .016862
REMARKS:

Figure 49 - Test Report of Experiment No. 42

U. S. ARMY FUELS & LUBRICANTS RESEARCH LABORATORY
TURBINE COMBUSTOR FACILITY

*** STUDY OF FUEL EMULSIONS FOR THE REDUCTION OF EXHAUST PARTICULATES ***
U.S. NAVY AIR ENGINEERING CENTER

DATE: 6/22/76 TIME: 9:10
COMBUSTOR SYSTEM: T-63 POWER POINT: 75%
TEST FUEL: JP5-HBR EMULSIFIED WITH 30% WATER

***** EXPERIMENTAL TEST CONDITIONS *****

	AVERAGE	STD.DEV.	DESIRED	LAST SCAN
INLET AIR PRESSURE, PSIA	57.33	.16	57.40	57.60
INLET AIR TEMPERATURE, DEG F	471.98	1.19	472.00	473.60
AIR FLOW RATE, LBS/SEC	2.089	.015	2.110	2.167
FUEL FLOW RATE, LBS/MIN	2.729	.020	2.730	2.759
FUEL/AIR RATIO	.02177	.00019	.02160	.02182
AIR FLOW LOADING FACTOR	1.1127	.0083	1.1230	1.1178

FUEL PRESSURE= 285
FUEL TEMPERATURE=124.1 DEG F

* BURNER OUTLET TEMPERATURE SURVEY *

BOT AVG=1465.7 DEG F
BOT HOT SPOT: TC# 3 = 1622 DEG F
BOT PATTERN FACTOR = .1578

	TC#	AVERAGE	STD DEV
OUTER ANNULUS	1	1538	12
	4	1508	15
	7	0	25
	10	1333	8
	13	1355	8
CENTER ANNULUS	2	1618	12
	5	1472	23
	8	1516	10
	11	1410	11
	14	1495	9
INNER ANNULUS	3	1622	12
	6	1388	28
	9	1361	10
	12	1364	16
	15	1541	7

* EXHAUST CHEMISTRY *

CO.. .104 % CO2..3.60 % O2..16.1 % UBH. 101.3. PPM <PROPANE>
NO.. 20.5 PPM NOX.. 25.0 PPM NO2.. 4.5 PPM <NOX-NO>
SMOKE NUMBER: 7.6

COMBUSTION EFFICIENCY, CALCULATED FROM EXHAUST CHEMISTRY: 97.8667
FUEL/AIR RATIO,CALCULATED FROM EXHAUST CHEMISTRY: .017528
REMARKS:

Figure 50 - Test Report of Experiment No. 43

U. S. ARMY FUELS & LUBRICANTS RESEARCH LABORATORY
TURBINE COMBUSTOR FACILITY

*** STUDY OF FUEL EMULSIONS FOR THE REDUCTION OF EXHAUST PARTICULATES *
U.S. NAVY AIR ENGINEERING CENTER

DATE: 6/22/76 TIME: 9:48
COMBUSTOR SYSTEM: T-63 POWER POINT: 55%
TEST FUEL: JP5-HBR

***** EXPERIMENTAL TEST CONDITIONS *****

	AVERAGE	STD.DEV.	DESIRED	LAST SCAN
INLET AIR PRESSURE, PSIA	50.92	.16	50.70	50.60
INLET AIR TEMPERATURE, DEG F	428.15	1.04	430.00	426.97
AIR FLOW RATE, LBS/SEC	1.931	.012	1.950	1.932
FUEL FLOW RATE, LBS/MIN	1.692	.014	1.690	1.660
FUEL/AIR RATIO	.01460	.00016	.01450	.01432
AIR FLOW LOADING FACTOR	1.1304	.0076	1.1470	1.1372

FUEL PRESSURE= 210
FUEL TEMPERATURE=137.1 DEG F

* BURNER OUTLET TEMPERATURE SURVEY *

BOT AVG=1275.8 DEG F
BOT HOT SPOT: TC# 2 = 1482 DEG F
BOT PATTERN FACTOR = .2433

	TC#	AVERAGE	STD DEV
OUTER ANNULUS	1	1419	12
	4	1316	13
	7	0	8
	10	1120	9
	13	1230	8
CENTER ANNULUS	2	1482	12
	5	1208	64
	8	1206	21
	11	1217	7
	14	1349	8
INNER ANNULUS	3	1461	13
	6	1165	27
	9	1201	7
	12	1089	39
	15	1399	10

* EXHAUST CHEMISTRY *

CO.. .084 % CO2..3.07 % O2..16.6 % UBH..75.7 PPM <PROPANE>
NO.. 22.5 PPM NOX.. 30.3 PPM NO2.. 7.8 PPM <NOX-NO>
SMOKE NUMBER: 19.0

COMBUSTION EFFICIENCY, CALCULATED FROM EXHAUST CHEMISTRY: 98.0293
FUEL/AIR RATIO,CALCULATED FROM EXHAUST CHEMISTRY: .015122
REMARKS:

Figure 51 - Test Report of Experiment No. 44

U. S. ARMY FUELS & LUBRICANTS RESEARCH LABORATORY
TURBINE COMBUSTOR FACILITY

*** STUDY OF FUEL EMULSIONS FOR THE REDUCTION OF EXHAUST PARTICULATES ***
U.S. NAVY AIR ENGINEERING CENTER

DATE: 6/22/76 TIME: 10:22
COMBUSTOR SYSTEM: T-63 POWER POINT: 55%
TEST FUEL: JP5-HBR EMULSIFIED WITH 15% WATER

***** EXPERIMENTAL TEST CONDITIONS *****

	AVERAGE	STD.DEV.	DESIRED	LAST SCAN
INLET AIR PRESSURE, PSIA	50.82	.12	50.70	50.80
INLET AIR TEMPERATURE, DEG F	427.86	1.17	430.00	426.32
AIR FLOW RATE, LBS/SEC	1.946	.010	1.950	1.945
FUEL FLOW RATE, LBS/MIN	1.933	.020	1.940	1.911
FUEL/AIR RATIO	.01656	.00019	.01670	.01638
AIR FLOW LOADING FACTOR	1.1406	.0061	1.1470	1.1399

FUEL PRESSURE= 222
FUEL TEMPERATURE=134.9 DEG F

* BURNER OUTLET TEMPERATURE SURVEY *

BOT AVG=1233.3 DEG F
BOT HOT SPOT: TC# 2 = 1449 DEG F
BOT PATTERN FACTOR = .2674

	TC#	AVERAGE	STD DEV
OUTER ANNULUS	1	1397	11
	4	1231	67
	7	0	4
	10	1109	11
	13	1189	8
CENTER ANNULUS	2	1449	11
	5	1066	62
	8	1154	16
	11	1187	11
	14	1314	10
INNER ANNULUS	3	1430	13
	6	1109	40
	9	1221	7
	12	1043	32
	15	1367	12

* EXHAUST CHEMISTRY *

CO.. .109 % CO2..3.00 % O2..16.5 % UBH.158.0 PPM <PROPANE>
NO.. 18.5 PPM NOX.. 23.8 PPM NO2.. 5.3 PPM <NOX-NO>
SMOKE NUMBER: 9.9

COMBUSTION EFFICIENCY, CALCULATED FROM EXHAUST CHEMISTRY: 96.8650
FUEL/AIR RATIO,CALCULATED FROM EXHAUST CHEMISTRY: .015154
REMARKS:

Figure 52 - Test Report of Experiment No. 45

U. S. ARMY FUELS & LUBRICANTS RESEARCH LABORATORY
TURBINE COMBUSTOR FACILITY

*** STUDY OF FUEL EMULSIONS FOR THE REDUCTION OF EXHAUST PARTICULATES ***
U.S. NAVY AIR ENGINEERING CENTER

DATE: 6/22/76 TIME: 10:44
COMBUSTOR SYSTEM: T-63 POWER POINT: 55%
TEST FUEL: JP5-HBR EMULSIFIED WITH 30% WATER

***** EXPERIMENTAL TEST CONDITIONS *****

	AVERAGE	STD.DEV.	DESIRED	LAST SCAN
INLET AIR PRESSURE, PSIA	51.06	.18	50.70	51.30
INLET AIR TEMPERATURE, DEG F	429.57	1.19	430.00	423.70
AIR FLOW RATE, LBS/SEC	1.942	.012	1.950	1.943
FUEL FLOW RATE, LBS/MIN	2.170	.019	2.190	2.165
FUEL/AIR RATIO	.01862	.00020	.01890	.01858
AIR FLOW LOADING FACTOR	1.1344	.0072	1.1470	1.1288

FUEL PRESSURE= 235
FUEL TEMPERATURE=129.3 DEG F

* BURNER OUTLET TEMPERATURE SURVEY *

BOT AVG=1248.0 DEG F
BOT HOT SPOT: TC# 2 = 1449 DEG F
BOT PATTERN FACTOR = .2455

	TC#	AVERAGE	STD DEV
OUTER ANNULUS	1	1398	12
	4	1285	20
	7	0	7
	10	1114	11
	13	1190	7
CENTER ANNULUS	2	1449	12
	5	1079	77
	8	1208	15
	11	1199	9
	14	1319	9
INNER ANNULUS	3	1397	15
	6	1103	39
	9	1237	9
	12	1132	18
	15	1363	10

* EXHAUST CHEMISTRY *

CO.. .121 % CO2..3.05 % O2..16.7 % UBH. 194.3 PPM <PROPANE>
NO.. 15.3 PPM NOX.. 18.8 PPM NO2.. 3.5 PPM <NOX-NO>
SMOKE NUMBER: 5.9

COMBUSTION EFFICIENCY, CALCULATED FROM EXHAUST CHEMISTRY: 96.4240
FUEL/AIR RATIO,CALCULATED FROM EXHAUST CHEMISTRY: .015296
REMARKS:

Figure 53 - Test Report of Experiment No. 46

U. S. ARMY FUELS & LUBRICANTS RESEARCH LABORATORY
TURBINE COMBUSTOR FACILITY

*** STUDY OF FUEL EMULSIONS FOR THE REDUCTION OF EXHAUST PARTICULATES **
U.S. NAVY AIR ENGINEERING CENTER

DATE: 6/23/76 TIME: 9:38
COMBUSTOR SYSTEM: T-63 POWER POINT: 40%
TEST FUEL: JP5-HBR EMULSIFIED WITH 0% WATER

***** EXPERIMENTAL TEST CONDITIONS *****

	AVERAGE	STD.DEV.	DESIRED	LAST SCAN
INLET AIR PRESSURE, PSIA	45.75	.43	42.10	45.40
INLET AIR TEMPERATURE, DEG F	401.16	1.19	397.00	400.85
AIR FLOW RATE, LBS/SEC	1.818	.023	1.790	1.801
FUEL FLOW RATE, LBS/MIN	1.423	.023	1.400	1.414
FUEL/AIR RATIO	.01305	.00024	.01310	.01309
AIR FLOW LOADING FACTOR	1.1661	.0135	1.1630	1.1638

FUEL PRESSURE= 190
FUEL TEMPERATURE=133.6 DEG F

* BURNER OUTLET TEMPERATURE SURVEY *

BOT AVG=1241.3 DEG F
BOT HOT SPOT: TC# 2 = 1382 DEG F
BOT PATTERN FACTOR = .1676

	TC#	AVERAGE	STD DEV
OUTER ANNULUS	1	1285	14
	4	1236	18
	7	0	46
	10	0	17
	13	1100	9
CENTER ANNULUS	2	1382	14
	5	1231	14
	8	1288	10
	11	1111	12
	14	1238	11
INNER ANNULUS	3	1380	17
	6	1242	25
	9	1217	19
	12	1136	12
	15	1291	12

* EXHAUST CHEMISTRY *

CO.. .091 % CO2..2.76 % O2..17.2 % UBH. 112.3 PPM <PROPANE>
NO.. 15.4 PPM NOX.. 21.2 PPM NO2.. 5.8 PPM <NOX-NO>
SMOKE NUMBER: 13.3

COMBUSTION EFFICIENCY, CALCULATED FROM EXHAUST CHEMISTRY: 97.3384
FUEL/AIR RATIO,CALCULATED FROM EXHAUST CHEMISTRY: .013637
REMARKS:

Figure 54 - Test Report of Experiment No. 47

U. S. ARMY FUELS & LUBRICANTS RESEARCH LABORATORY
TURBINE COMBUSTOR FACILITY

** STUDY OF FUEL EMULSIONS FOR THE REDUCTION OF EXHAUST PARTICULATES **
U.S. NAVY AIR ENGINEERING CENTER

DATE: 6/28/76 TIME: 10: 7
COMBUSTOR SYSTEM: T-63 POWER POINT: 40%
TEST FUEL: JP5-HBR EMULSIFIED WITH 15% WATER

***** EXPERIMENTAL TEST CONDITIONS *****

	AVERAGE	STD.DEV.	DESIRED	LAST SCAN
INLET AIR PRESSURE, PSIA	44.19	.28	45.10	44.00
INLET AIR TEMPERATURE, DEG F	398.12	1.17	397.00	397.62
AIR FLOW RATE, LBS/SEC	1.777	.025	1.790	1.758
FUEL FLOW RATE, LBS/MIN	1.595	.021	1.610	1.600
FUEL/AIR RATIO	.01497	.00017	.01510	.01517
AIR FLOW LOADING FACTOR	1.1779	.0129	1.1630	1.1702

FUEL PRESSURE= 200
FUEL TEMPERATURE=134.9 DEG F

* BURNER OUTLET TEMPERATURE SURVEY *

BOT AVG=1221.6 DEG F
BOT HOT SPOT: TC# 2 = 1363 DEG F
BOT PATTERN FACTOR = .1721

	TC#	AVERAGE	STD DEV
OUTER ANNULUS	1	1266	16
	4	1215	11
	7	1176	8
	10	0	11
	13	1083	7
CENTER ANNULUS	2	1363	16
	5	1200	10
	8	1206	11
	11	1090	11
	14	1220	10
INNER ANNULUS	3	1357	15
	6	1236	10
	9	1209	8
	12	1116	9
	15	1278	12

* EXHAUST CHEMISTRY *

CO.. .120 % CO2..2.76 % O2..17.0 % UBH. 200.0 PPM <PROPANE>
NO.. 12.8 PPM NOX.. 16.8 PPM NO2.. 4.0 PPM <NOX-NO>
SMOKE NUMBER: 5.2

COMBUSTION EFFICIENCY, CALCULATED FROM EXHAUST CHEMISTRY: 96.0315
FUEL/AIR RATIO,CALCULATED FROM EXHAUST CHEMISTRY: .014011
REMARKS:

Figure 55 - Test Report of Experiment No. 48

U. S. ARMY FUELS & LUBRICANTS RESEARCH LABORATORY
TURBINE COMBUSTOR FACILITY

*** STUDY OF FUEL EMULSIONS FOR THE REDUCTION OF EXHAUST PARTICULATES *
U.S. NAVY AIR ENGINEERING CENTER

DATE: 6/28/76 TIME: 10:38
COMBUSTOR SYSTEM: T-63 POWER POINT: 40%
TEST FUEL: JP5-HBR EMULSIFIED WITH 30% WATER

***** EXPERIMENTAL TEST CONDITIONS *****

	AVERAGE	STD.DEV.	DESIRED	LAST SCAN
INLET AIR PRESSURE, PSIA	45.82	.41	1.16	46.30
INLET AIR TEMPERATURE, DEG F	398.70	1.20	~~12.00~~	399.13
AIR FLOW RATE, LBS/SEC	1.821	.026	4.000	1.788
FUEL FLOW RATE, LBS/MIN	1.840	.018	600.000	1.843
FUEL/AIR RATIO	.01685	.00033	.12000	.01718
AIR FLOW LOADING FACTOR	1.1643	.0120	2.7600	1.1317

FUEL PRESSURE= 212
FUEL TEMPERATURE=128.9 DEG F

* BURNER OUTLET TEMPERATURE SURVEY *

BOT AVG=1190.7 DEG F
BOT HOT SPOT: TC# 2 = 1331 DEG F
BOT PATTERN FACTOR = .1770

	TC#	AVERAGE	STD DEV
OUTER ANNULUS	1	1241	18
	4	1199	16
	7	1104	28
	10	0	11
	13	1072	12
CENTER ANNULUS	2	1331	18
	5	1181	13
	8	1241	15
	11	1079	15
	14	1191	13
INNER ANNULUS	3	1327	17
	6	1198	14
	9	1171	13
	12	1094	13
	15	1241	15

* EXHAUST CHEMISTRY *

CO.. .136 % CO2..2.70 % O2..17.0 % UBH. 270.3 PPM <PROPANE>
NO.. 10.2 PPM NOX.. 12.7 PPM NO2.. 2.5 PPM <NOX-NO>
SMOKE NUMBER: 3.3

COMBUSTION EFFICIENCY, CALCULATED FROM EXHAUST CHEMISTRY: 95.0206
FUEL/AIR RATIO, CALCULATED FROM EXHAUST CHEMISTRY: .013050
REMARKS:

Figure 56 - Test Report of Experiment No. 49

U. S. ARMY FUELS & LUBRICANTS RESEARCH LABORATORY
TURBINE COMBUSTOR FACILITY

* * STUDY OF FUEL EMULSIONS FOR THE REDUCTION OF EXHAUST PARTICULATES --
U.S. NAVY AIR ENGINEERING CENTER

DATE: 6/28/76 TIME: 11:13
COMBUSTOR SYSTEM: T-63 POWER POINT: 25%
TEST FUEL: JP5-HBR

***** EXPERIMENTAL TEST CONDITIONS *****

	AVERAGE	STD.DEV.	DESIRED	LAST SCAN
INLET AIR PRESSURE, PSIA	39.01	.15	38.80	38.70
INLET AIR TEMPERATURE, DEG F	355.23	.68	353.00	354.23
AIR FLOW RATE, LBS/SEC	1.566	.009	1.560	1.560
FUEL FLOW RATE, LBS/MIN	1.147	.012	1.135	1.146
FUEL/AIR RATIO	.01221	.00014	.01210	.01225
AIR FLOW LOADING FACTOR	1.1462	.0082	1.1450	1.1499

FUEL PRESSURE= 175
FUEL TEMPERATURE=144.8 DEG F

* BURNER OUTLET TEMPERATURE SURVEY *

BOT AVG=1133.2 DEG F
BOT HOT SPOT: TC# 3 = 1264 DEG F
BOT PATTERN FACTOR = .1685

	TC#	AVERAGE	STD DEV
OUTER ANNULUS	1	1162	10
	4	1150	8
	7	1110	6
	10	0	6
	13	1017	7
CENTER ANNULUS	2	1247	10
	5	1132	7
	8	1177	10
	11	1002	9
	14	1120	7
INNER ANNULUS	3	1264	12
	6	1158	7
	9	1124	6
	12	1028	7
	15	1172	8

* EXHAUST CHEMISTRY *

CO.. .114 % CO2..2.52 % O2..17.4 % UBH. 163.7 PPM <PROPANE>
NO.. 11.0 PPM NOX.. 15.3 PPM NO2.. 4.3 PPM <NOX-NO>
SMOKE NUMBER: 7.3

COMBUSTION EFFICIENCY, CALCULATED FROM EXHAUST CHEMISTRY: 96.1639
FUEL/AIR RATIO, CALCULATED FROM EXHAUST CHEMISTRY: .012763
REMARKS:

Figure 57 - Test Report of Experiment No. 50

U. S. ARMY FUELS & LUBRICANTS RESEARCH LABORATORY
TURBINE COMBUSTOR FACILITY

** STUDY OF FUEL EMULSIONS FOR THE REDUCTION OF EXHAUST PARTICULATES **
U.S. NAVY AIR ENGINEERING CENTER

DATE: 3/28/76 TIME: 11:38
COMBUSTOR SYSTEM: T-63 POWER POINT: 25%
TEST FUEL: JP5-HBR EMULSIFIED WITH 15% WATER

***** EXPERIMENTAL TEST CONDITIONS *****

	AVERAGE	STD.DEV.	DESIRED	LAST SCAN
INLET AIR PRESSURE, PSIA	39.09	.14	38.80	39.20
INLET AIR TEMPERATURE, DEG F	356.58	.88	353.00	357.03
AIR FLOW RATE, LBS/SEC	1.567	.009	1.560	1.560
FUEL FLOW RATE, LBS/MIN	1.292	.021	1.290	1.271
FUEL/AIR RATIO	.01374	.00025	.01390	.01358
AIR FLOW LOADING FACTOR	1.1456	.0086	1.1450	1.1377

FUEL PRESSURE= 105
FUEL TEMPERATURE=142.3 DEG F

* BURNER OUTLET TEMPERATURE SURVEY *

BOT AVG=1116.0 DEG F
BOT HOT SPOT: TC# 3 = 1240 DEG F
BOT PATTERN FACTOR = .1637

	TC#	AVERAGE	STD DEV
OUTER ANNULUS	1	1155	14
	4	1118	11
	7	1098	10
	10	0	8
	13	1007	9
CENTER ANNULUS	2	1230	14
	5	1106	10
	8	1159	13
	11	986	11
	14	1107	11
INNER ANNULUS	3	1240	16
	6	1136	11
	9	1107	11
	12	1014	10
	15	1161	11

* EXHAUST CHEMISTRY *

CO.. .135 % CO2..2.30 % O2..17.5 % UBH.286.7 PPM (PROPANE)
NO.. 9.3 PPM NOX.. 12.3 PPM NO2.. 3.0 PPM (NOX-NO)
SMOKE NUMBER: 3.4

COMBUSTION EFFICIENCY, CALCULATED FROM EXHAUST CHEMISTRY: 94.4994
FUEL/AIR RATIO,CALCULATED FROM EXHAUST CHEMISTRY: .012808
REMARKS:

Figure 58 - Test Report of Experiment No. 51

U. S. ARMY FUELS & LUBRICANTS RESEARCH LABORATORY
TURBINE COMBUSTOR FACILITY

** STUDY OF FUEL EMULSIONS FOR THE REDUCTION OF EXHAUST PARTICULATES **
U.S. NAVY AIR ENGINEERING CENTER

DATE: 3/28/76 TIME: 12:10
COMBUSTOR SYSTEM: T-63 POWER POINT: 25%
TEST FUEL: JP5-HBR EMULSIFIED WITH 30% WATER

***** EXPERIMENTAL TEST CONDITIONS *****

	AVERAGE	STD.DEV.	DESIRED	LAST SCAN
INLET AIR PRESSURE, PSIA	39.24	.13	38.80	39.20
INLET AIR TEMPERATURE, DEG F	356.91	.77	353.00	355.95
AIR FLOW RATE, LBS/SEC	1.563	.009	1.560	1.564
FUEL FLOW RATE, LBS/MIN	1.443	.012	1.460	1.434
FUEL/AIR RATIO	.01539	.00015	.01570	.01528
AIR FLOW LOADING FACTOR	1.1384	.0077	1.1450	1.1400

FUEL PRESSURE= 105
FUEL TEMPERATURE=139.7 DEG F

* BURNER OUTLET TEMPERATURE SURVEY *

BOT AVG=1082.2 DEG F
BOT HOT SPOT: TC# 3 = 1207 DEG F
BOT PATTERN FACTOR = .1716

	TC#	AVERAGE	STD DEV
OUTER ANNULUS	1	1122	11
	4	1082	7
	7	1053	6
	10	0	5
	13	986	6
CENTER ANNULUS	2	1197	11
	5	1066	6
	8	1101	8
	11	975	7
	14	1079	7
INNER ANNULUS	3	1207	13
	6	1091	6
	9	1068	6
	12	997	6
	15	1128	7

* EXHAUST CHEMISTRY *

CO.. .148 % CO2..2.35 % O2..17.5 % UBH.374.7 PPM (PROPANE)
NO.. 7.5 PPM NOX.. 9.5 PPM NO2.. 2.0 PPM (NOX-NO)
SMOKE NUMBER: 2.2

COMBUSTION EFFICIENCY, CALCULATED FROM EXHAUST CHEMISTRY: 93.0219
FUEL/AIR RATIO,CALCULATED FROM EXHAUST CHEMISTRY: .012406
REMARKS:

Figure 59 - Test Report of Experiment No. 52

U. S. ARMY FUELS & LUBRICANTS RESEARCH LABORATORY
TURBINE COMBUSTOR FACILITY

*** STUDY OF FUEL EMULSIONS FOR THE REDUCTION OF EXHAUST PARTICULATES **
U.S. NAVY AIR ENGINEERING CENTER

DATE: 6/28/76 TIME: 12:59
COMBUSTOR SYSTEM: T-63 POWER POINT: 10%
TEST FUEL: JP5-HBR

***** EXPERIMENTAL TEST CONDITIONS *****

	AVERAGE	STD.DEV.	DESIRED	LAST SCAN
INLET AIR PRESSURE, PSIA	33.46	.18	31.50	33.10
INLET AIR TEMPERATURE, DEG F	313.12	1.74	300.00	312.13
AIR FLOW RATE, LBS/SEC	1.376	.011	1.320	1.360
FUEL FLOW RATE, LBS/MIN	.871	.009	.867	.867
FUEL/AIR RATIO	.01055	.00015	.01090	.01057
AIR FLOW LOADING FACTOR	1.1431	.0120	1.1300	1.1406

FUEL PRESSURE= 162
FUEL TEMPERATURE=156.2 DEG F

* BURNER OUTLET TEMPERATURE SURVEY *

BOT AVG= 969.6 DEG F
BOT HOT SPOT: TC# 3 = 1087 DEG F
BOT PATTERN FACTOR = .1782

	TC#	AVERAGE	STD DEV
OUTER ANNULUS	1	977	10
	4	992	11
	7	941	11
	10	0	9
	13	890	10
CENTER ANNULUS	2	1056	10
	5	971	11
	8	979	11
	11	882	10
	14	961	11
INNER ANNULUS	3	1087	11
	6	983	13
	9	961	11
	12	898	10
	15	997	12

* EXHAUST CHEMISTRY *

CO.. .124 % CO2..2.05 % O2..18.0 % UBH. 200.7 PPM (PROPANE)
NO.. 6.8 PPM NOX.. 9.5 PPM NO2.. 2.7 PPM (NOX-NO)
SMOKE NUMBER: 6.8

COMBUSTION EFFICIENCY, CALCULATED FROM EXHAUST CHEMISTRY: 94.0701
FUEL AIR RATIO,CALCULATED FROM EXHAUST CHEMISTRY: .010740
REMARKS:

Figure 60 - Test Report of Experiment No. 53

U. S. ARMY FUELS & LUBRICANTS RESEARCH LABORATORY
TURBINE COMBUSTOR FACILITY

*** STUDY OF FUEL EMULSIONS FOR THE REDUCTION OF EXHAUST PARTICULATES **
U.S. NAVY AIR ENGINEERING CENTER

DATE: 6/28/76 TIME: 1:31
COMBUSTOR SYSTEM: T-63 POWER POINT: 10%
TEST FUEL: JP5-HBR EMULSIFIED WITH 15% WATER

***** EXPERIMENTAL TEST CONDITIONS *****

	AVERAGE	STD.DEV.	DESIRED	LAST SCAN
INLET AIR PRESSURE, PSIA	32.68	.33	31.50	32.50
INLET AIR TEMPERATURE, DEG F	318.33	.88	300.00	319.69
AIR FLOW RATE, LBS/SEC	1.348	.008	1.320	1.336
FUEL FLOW RATE, LBS/MIN	1.005	.036	.997	.988
FUEL/AIR RATIO	.01243	.00046	.01250	.01233
AIR FLOW LOADING FACTOR	1.1508	.0136	1.1500	1.1479

FUEL PRESSURE= 160
FUEL TEMPERATURE=155.2 DEG F

* BURNER OUTLET TEMPERATURE SURVEY *

BOT AVG= 978.3 DEG F
BOT HOT SPOT: TC# 3 = 1102 DEG F
BOT PATTERN FACTOR = .1880

	TC#	AVERAGE	STD DEV
OUTER ANNULUS	1	999	32
	4	993	32
	7	941	29
	10	0	21
	13	896	24
CENTER ANNULUS	2	1080	32
	5	969	31
	8	986	33
	11	989	24
	14	974	30
INNER ANNULUS	3	1102	37
	6	982	33
	9	965	31
	12	904	25
	15	1015	33

* EXHAUST CHEMISTRY *

CO.. .150 % CO2..2.00 % O2..18.1 % UBH. 437.7 PPM (PROPANE)
NO.. 5.3 PPM NOX.. 8.2 PPM NO2.. 2.9 PPM (NOX-NO)
SMOKE NUMBER: 2.9

COMBUSTION EFFICIENCY, CALCULATED FROM EXHAUST CHEMISTRY: 91.1468
FUEL AIR RATIO,CALCULATED FROM EXHAUST CHEMISTRY: .010068
REMARKS:

Figure 61 - Test Report of Experiment No. 54

U. S. ARMY FUELS & LUBRICANTS RESEARCH LABORATORY
TURBINE COMBUSTOR FACILITY

** STUDY OF FUEL EMULSIONS FOR THE REDUCTION OF EXHAUST PARTICULATES **
U.S. NAVY AIR ENGINEERING CENTER

DATE: 6/28/78 TIME: 1:57
COMBUSTOR SYSTEM: T-63 POWER POINT: 10%
TEST FUEL: JP5-HBR EMULSIFIED WITH 30% WATER

***** EXPERIMENTAL TEST CONDITIONS *****

	AVERAGE	STD.DEV.	DESIRED	LAST SCAN
INLET AIR PRESSURE, PSIA	32.60	.27	31.50	32.20
INLET AIR TEMPERATURE, DEG F	318.58	.92	300.00	317.53
AIR FLOW RATE, LBS/SEC	1.346	.008	1.320	1.340
FUEL FLOW RATE, LBS/MIN	1.113	.011	1.127	1.104
FUEL/AIR RATIO	.01378	.00017	.01420	.01373
AIR FLOW LOADING FACTOR	1.1519	.0122	1.1580	1.1607

FUEL PRESSURE= 170
FUEL TEMPERATURE=150.9 DEG F

* BURNER OUTLET TEMPERATURE SURVEY *

BOT AVG= 930.3 DEG F
BOT HOT SPOT: TC# 3 = 1049 DEG F
BOT PATTERN FACTOR = .1790

	TC#	AVERAGE	STD DEV
OUTER ANNULUS	1	972	12
	4	937	12
	7	892	10
	10	0	8
	13	870	9
CENTER ANNULUS	2	1041	12
	5	916	11
	8	932	13
	11	867	10
	14	942	11
INNER ANNULUS	3	1049	15
	6	929	11
	9	930	11
	12	878	10
	15	980	11

* EXHAUST CHEMISTRY *

CO.. .160 % CO2..1.95 % O2..18.1 % UBH. 511.3 PPM (PROPANE)
NO.. 4.4 PPM NOX.. 6.6 PPM NO2.. 2.2 PPM (NOX-NO)
SMOKE NUMBER: 1.8

COMBUSTION EFFICIENCY, CALCULATED FROM EXHAUST CHEMISTRY: 80.8932
FUEL/AIR RATIO,CALCULATED FROM EXHAUST CHEMISTRY: .010816
REMARKS:

Figure 62 - Test Report of Experiment No. 55

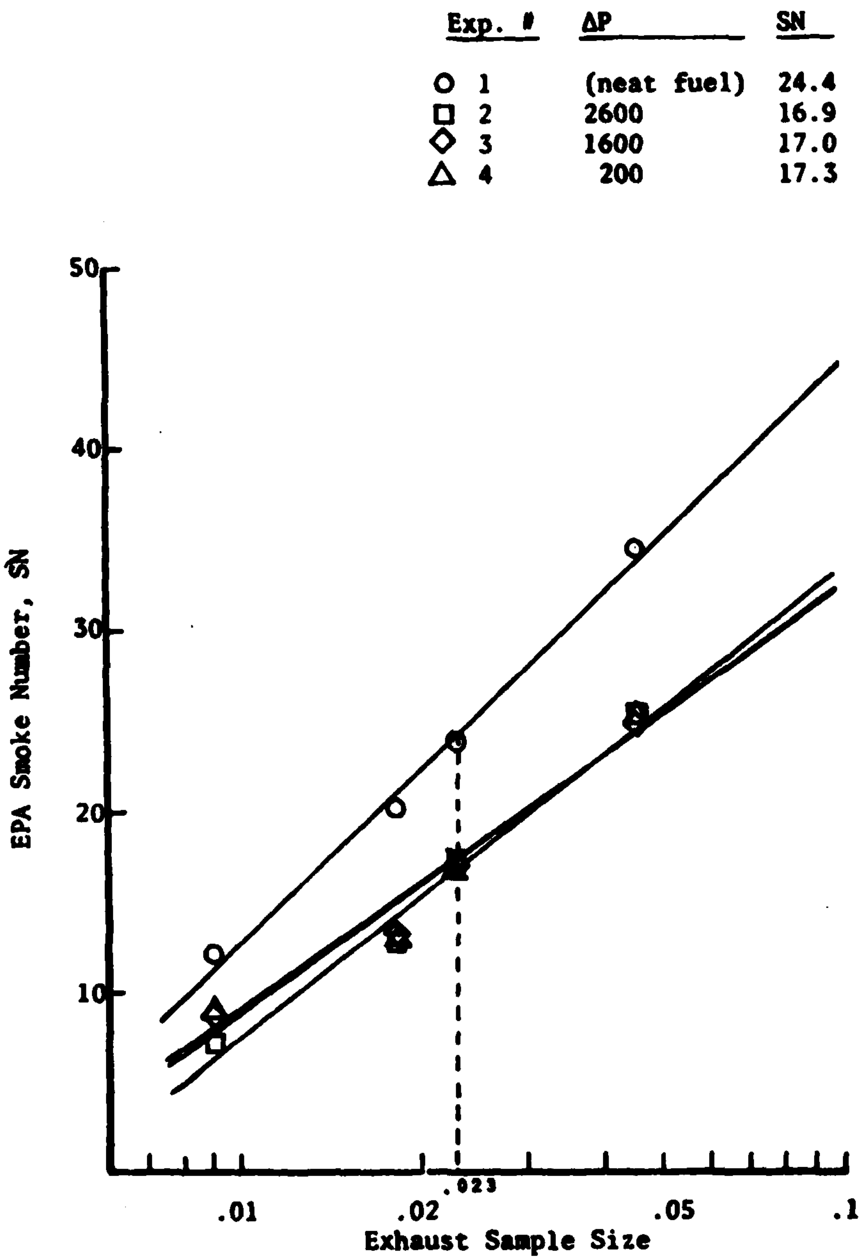


Figure 63 - Smoke Number Evaluations for Experiments 1, 2, 3, and 4 Showing the Effect of Homogenizer Pressure Drop on Smoke Reduction

Exp. #	Surfactant Concentration	SN
◇ 2	2.0	16.9
○ 5	0.0	25.5
△ 6	1.0	18.5
□ 7	0.5	21.5
▽ 8	0.0	27.1

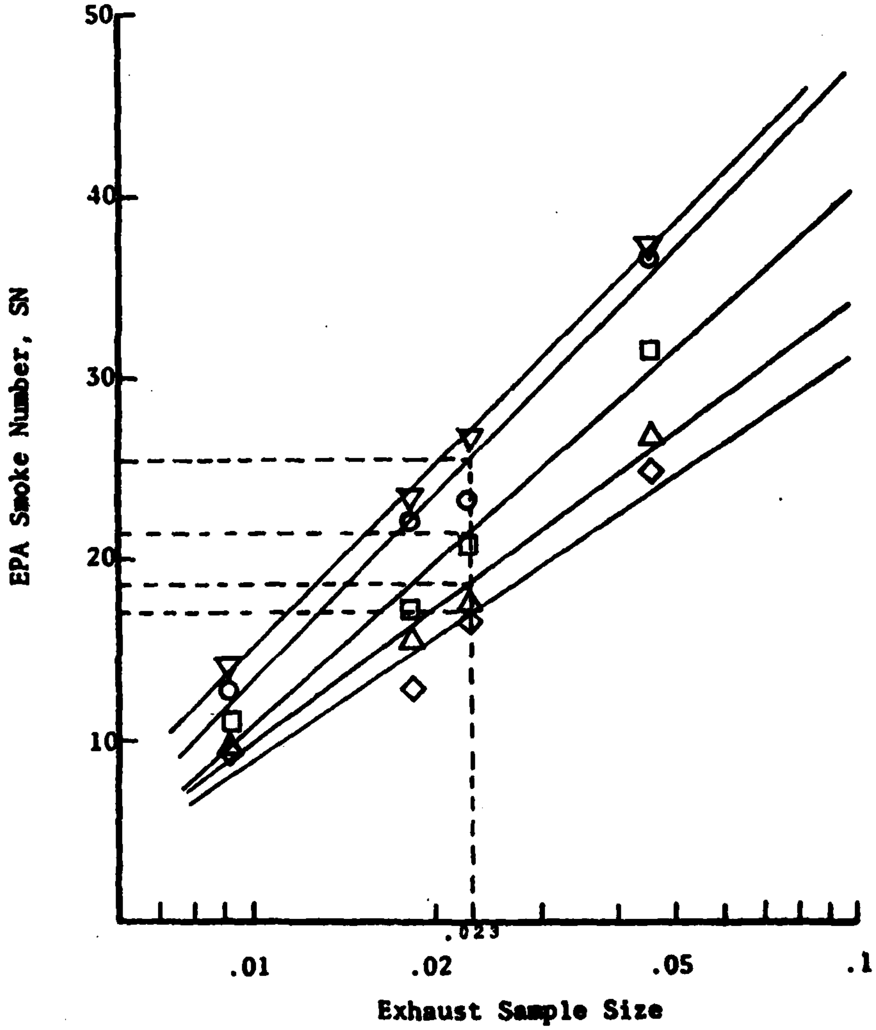


Figure 64 - Smoke Number Evaluations for Experiments 2, 5, 6, 7, and 8 Showing the Effect of Surfactant Concentration for an Emulsion of 10% Water

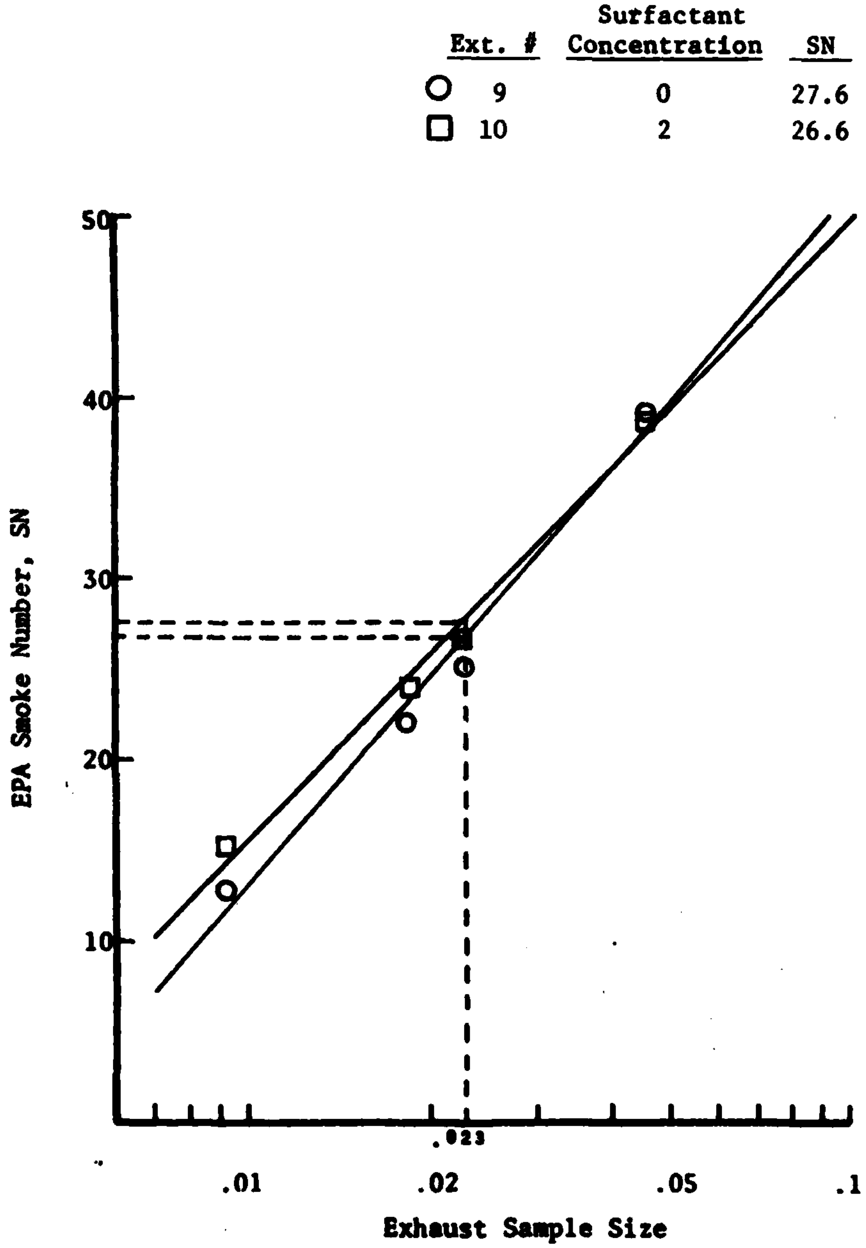


Figure 65 - Smoke Number Evaluations for Experiments 9 and 10 Showing the Effect of Just the Surfactant on Smoke Level

	Exp. #	Surfactant Concentration	SN
○	11	0.0	27.2
□	13	2.0	21.4
△	14	1.0	23.0
◇	15	0.5	24.0

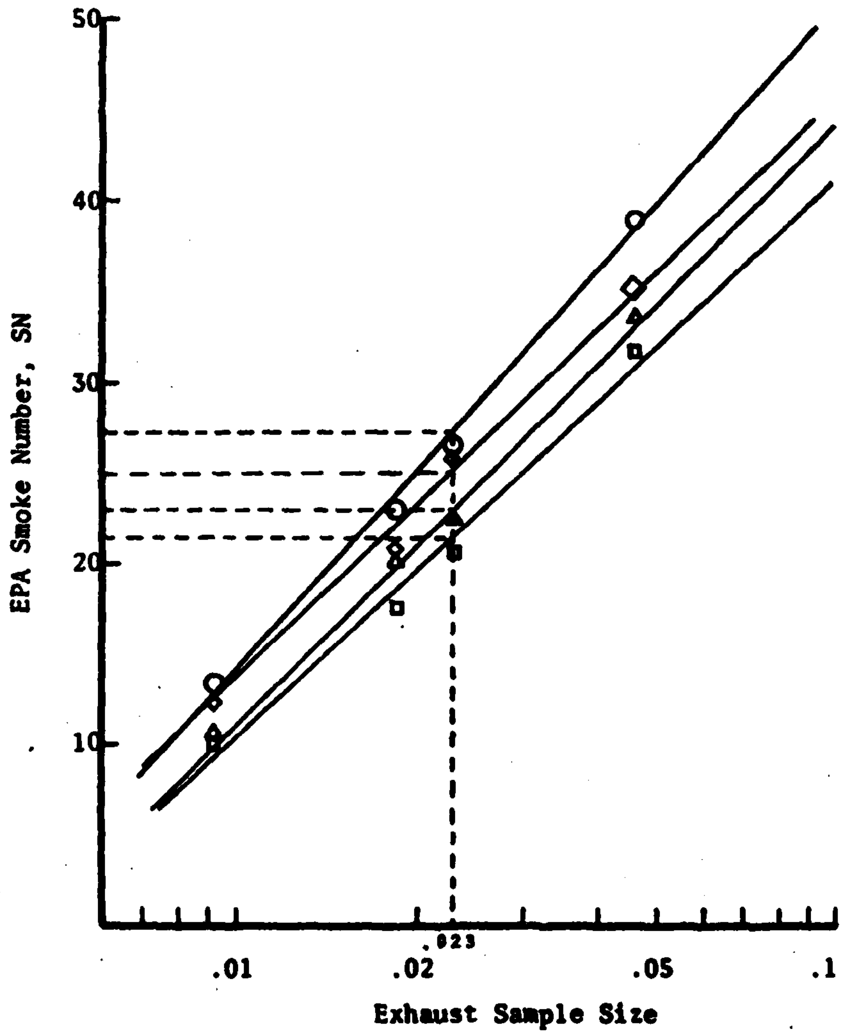


Figure 66 - Smoke Number Evaluations for Experiments 11, 13, 14, and 15 Showing the Effect of Surfactant Concentration for an Emulsion of 5% Water

Exp.#	Fuel System	SN
● 16	JP5-HA	33.6
○ 17	JP5-HA emulsified w/10% water	23.8
■ 18	JP5-HBR	25.0
□ 19	JP5-HBR emulsified w/10% water	15.4

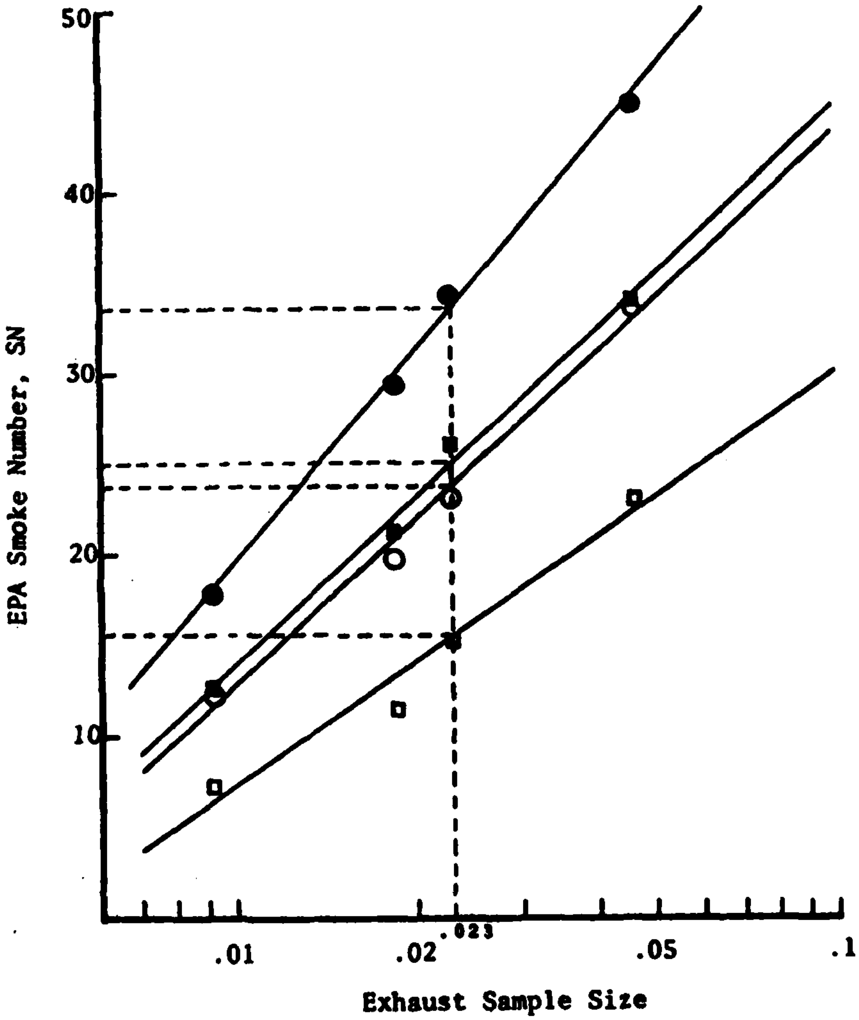


Figure 67 - Smoke Number Evaluations for Experiments 16, 17, 18, and 19 Showing Sensitivity of Concept to Fuel Type

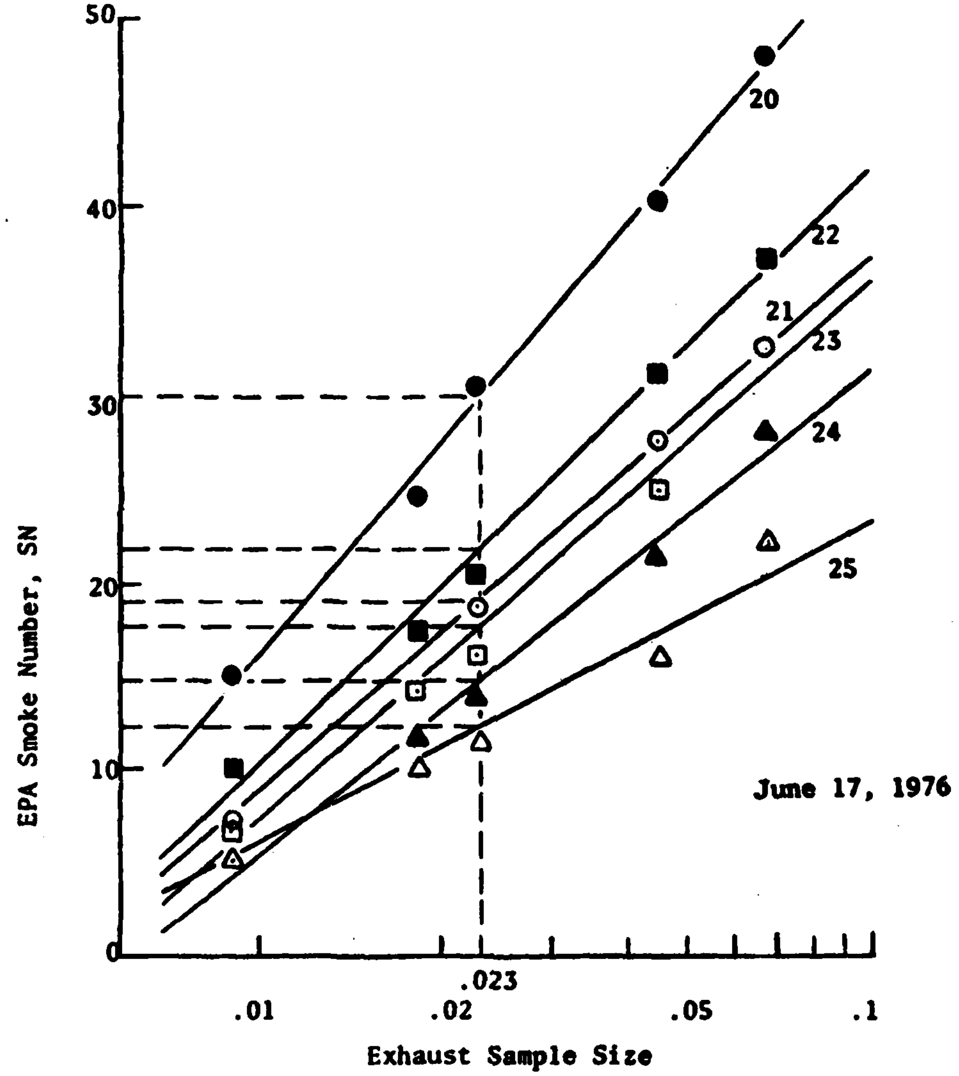


Figure 68 - Smoke Number Evaluations for Experiments 20, 21, 22, 23, 24, and 25

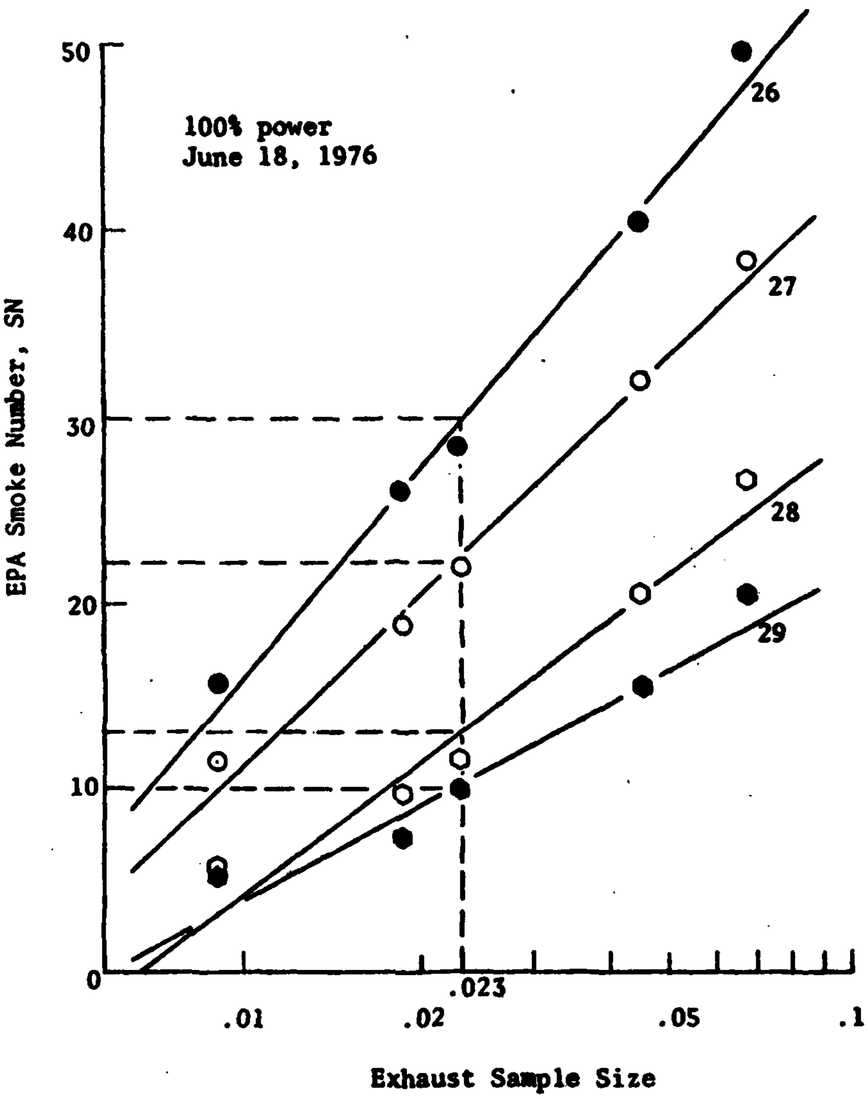


Figure 69 - Smoke Number Evaluations for Experiments 26, 27, 28, and 29

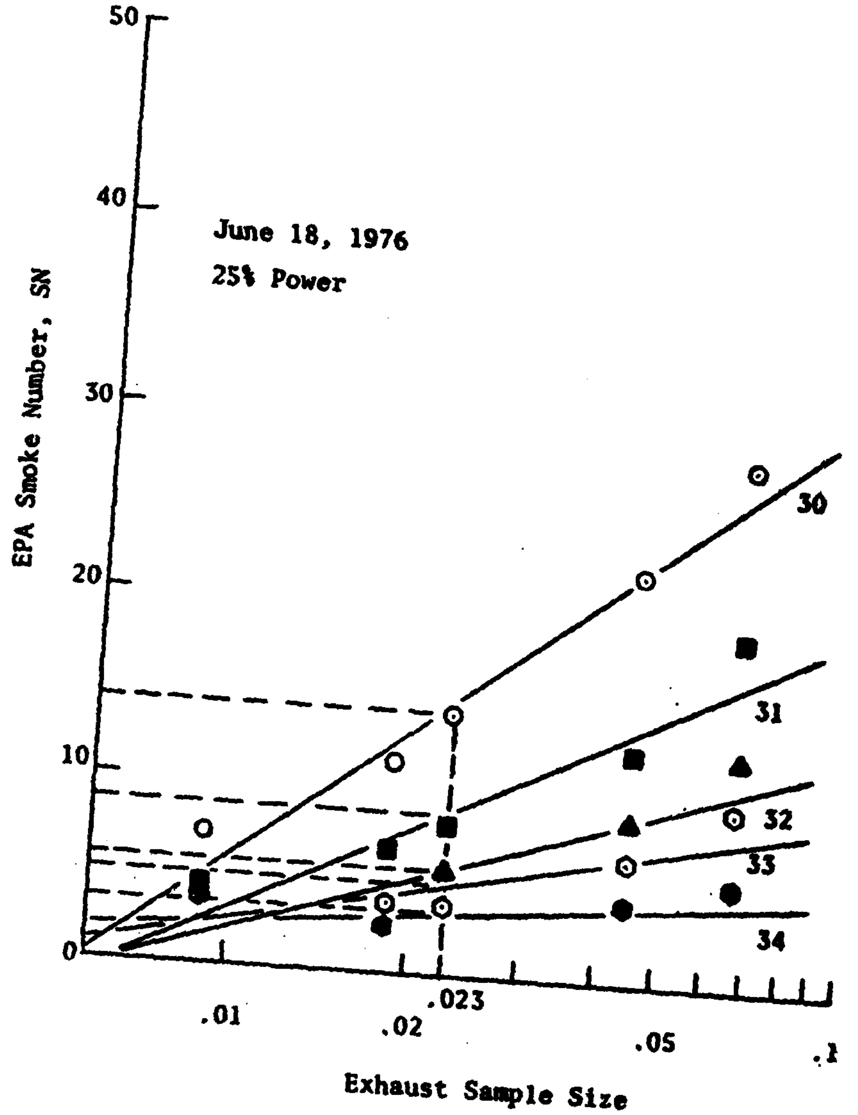


Figure 70 - Smoke Number Evaluations for Experiments 30, 31, 32, 33, and 34

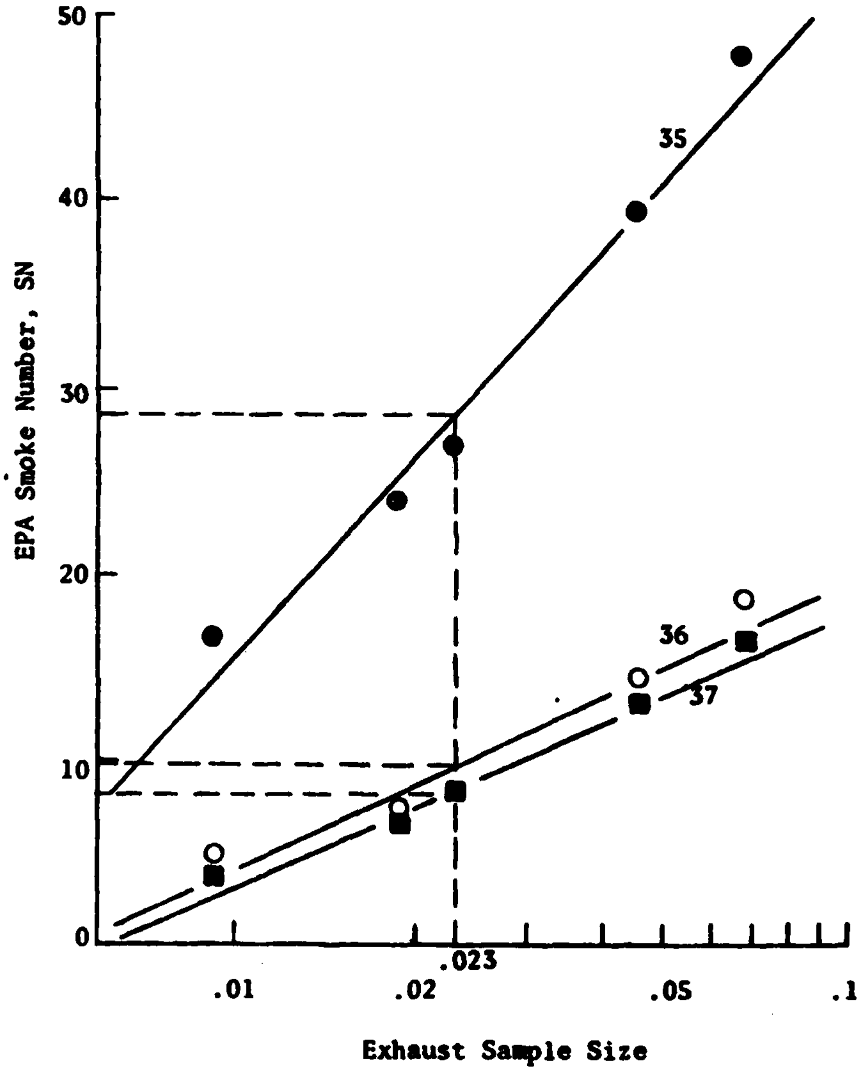


Figure 71 - Smoke Number Evaluations for Experiments 35, 36, and 37

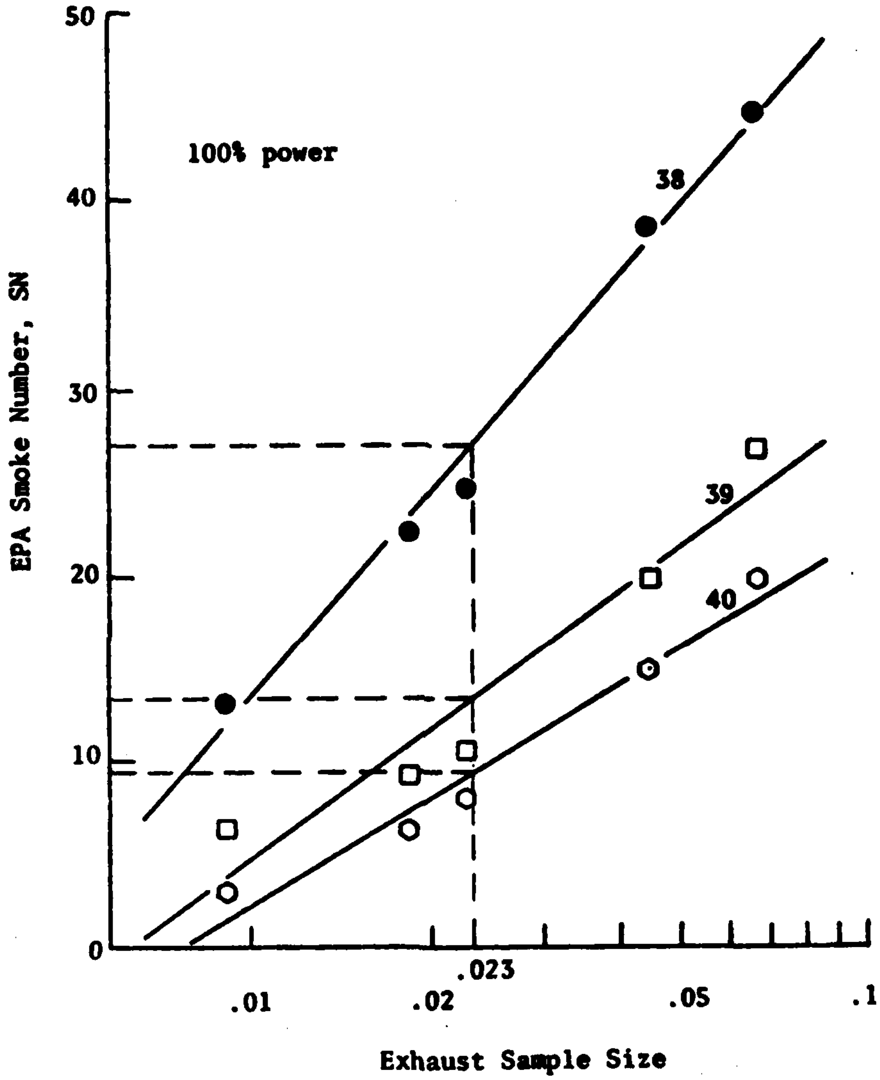


Figure 72 - Smoke Number Evaluations for Experiments 38, 39, and 40

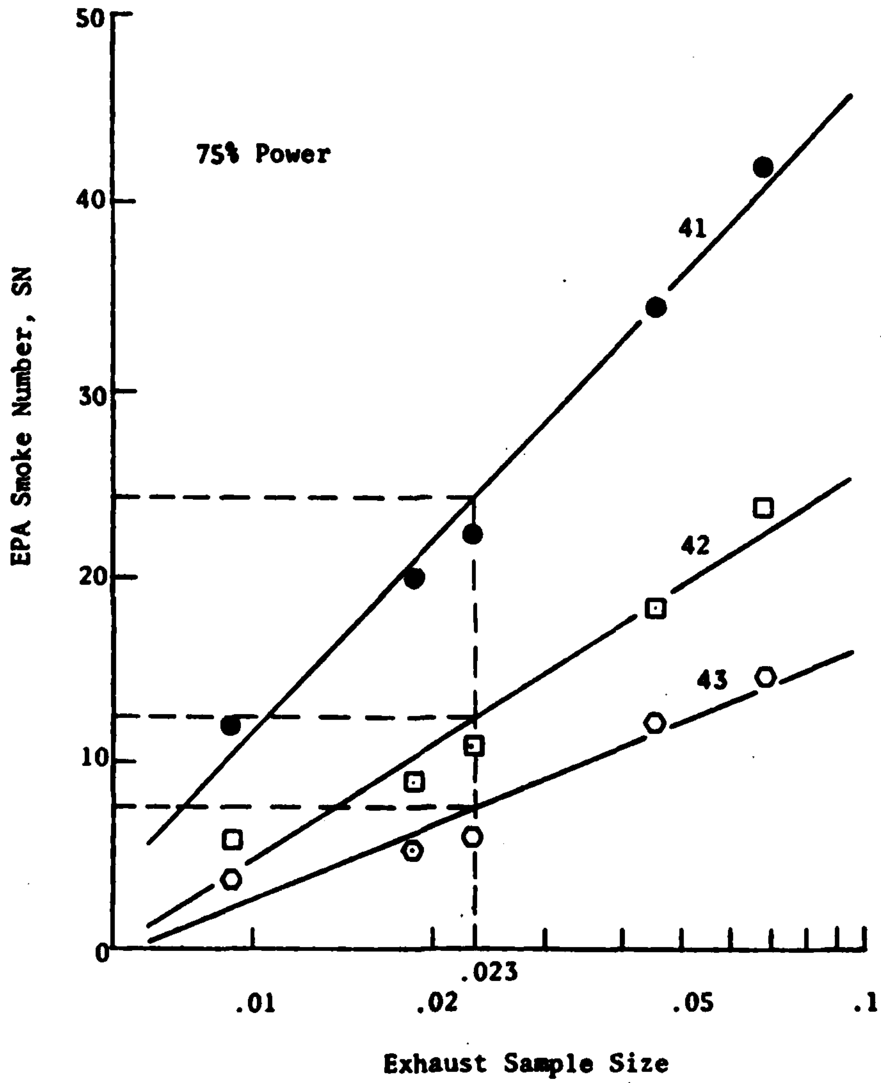


Figure 75 - Smoke Number Evaluations for Experiments 41, 42, and 43

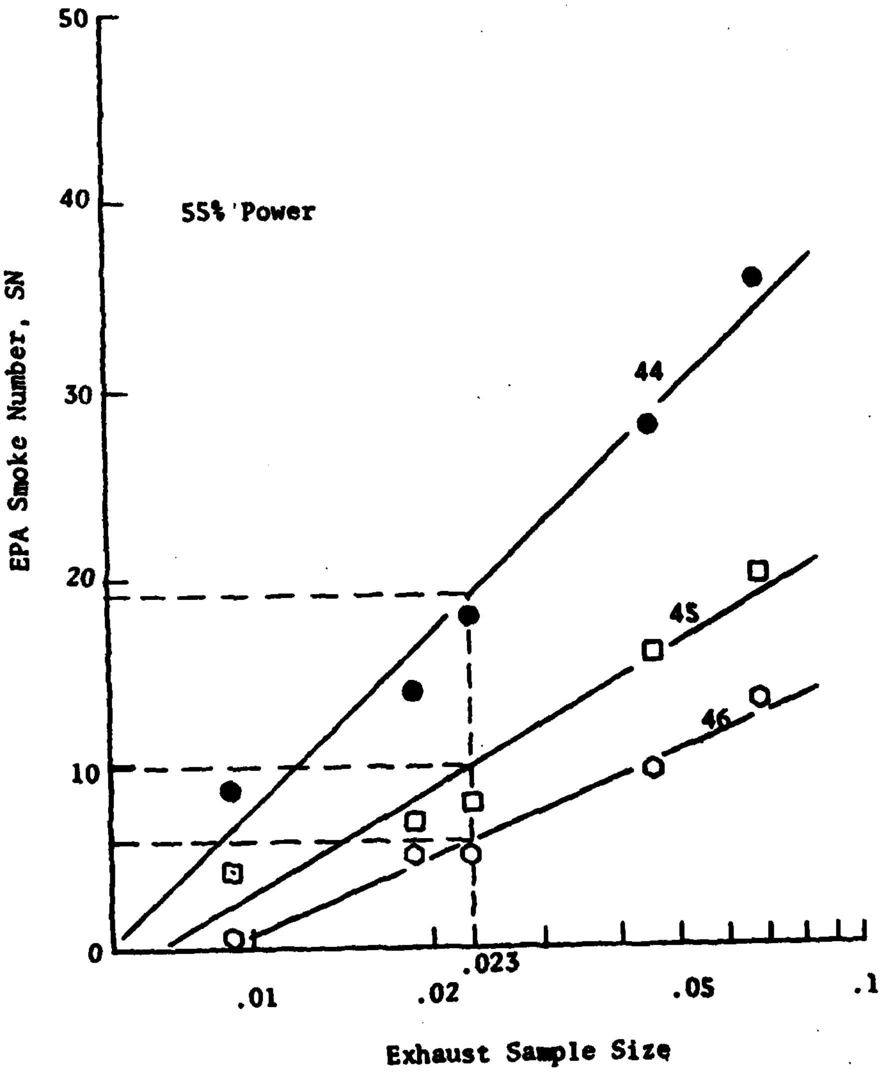


Figure 74 - Smoke Number Evaluations for Experiments 44, 45, and 46

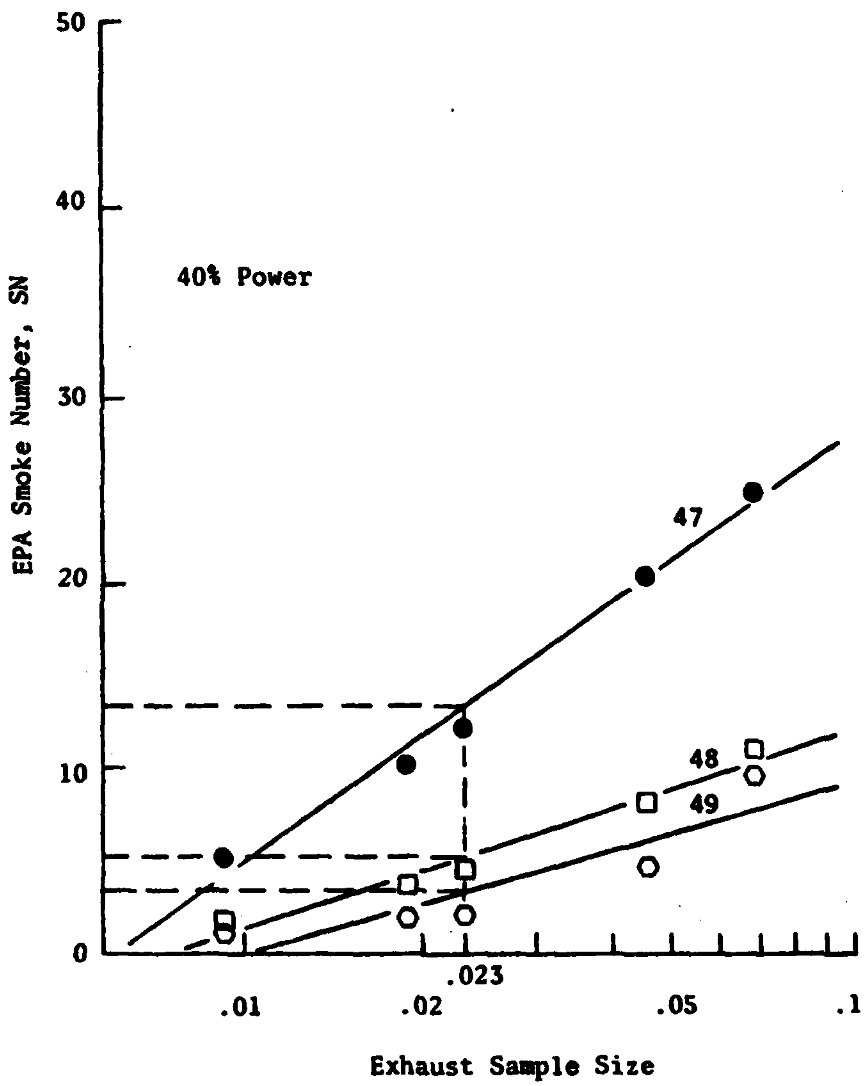


Figure 75 - Smoke Number Evaluations for Experiments 47, 48, and 49

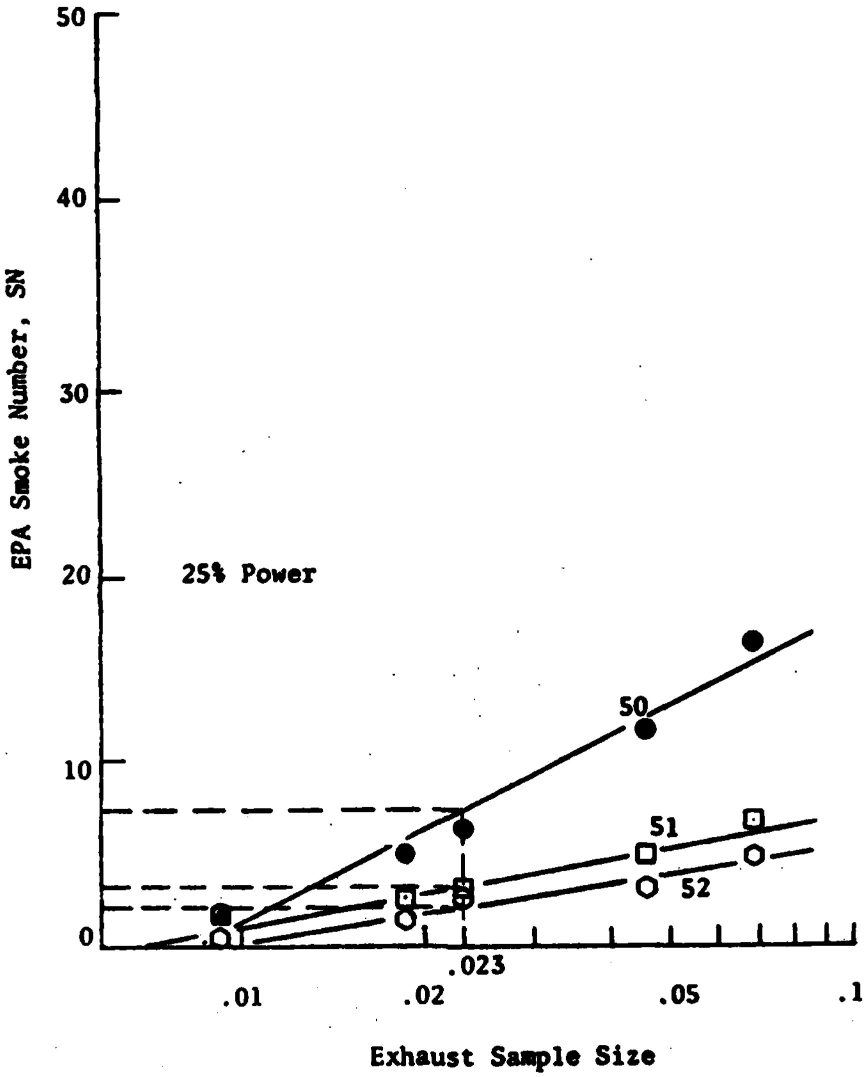


Figure 76 - Smoke Number Evaluations for Experiments 50, 51, and 52

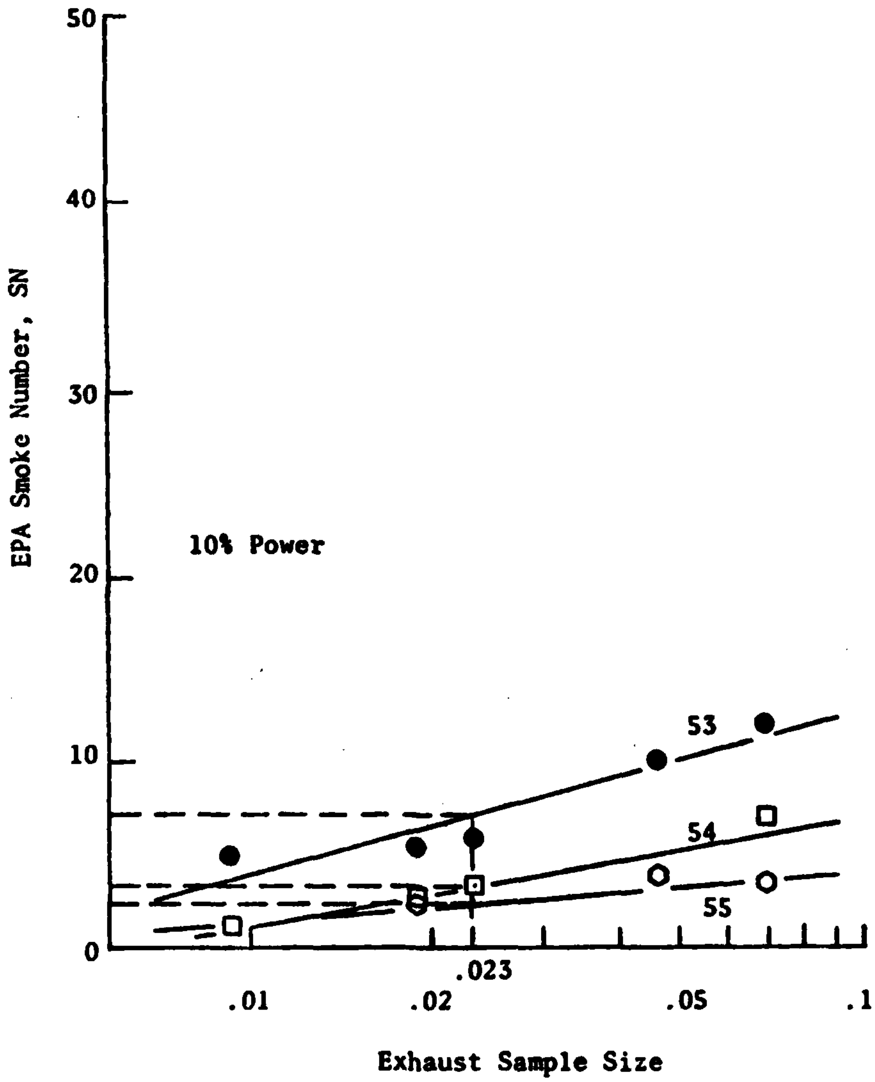


Figure 77 - Smoke Number Evaluations for Experiments 53, 54, and 55

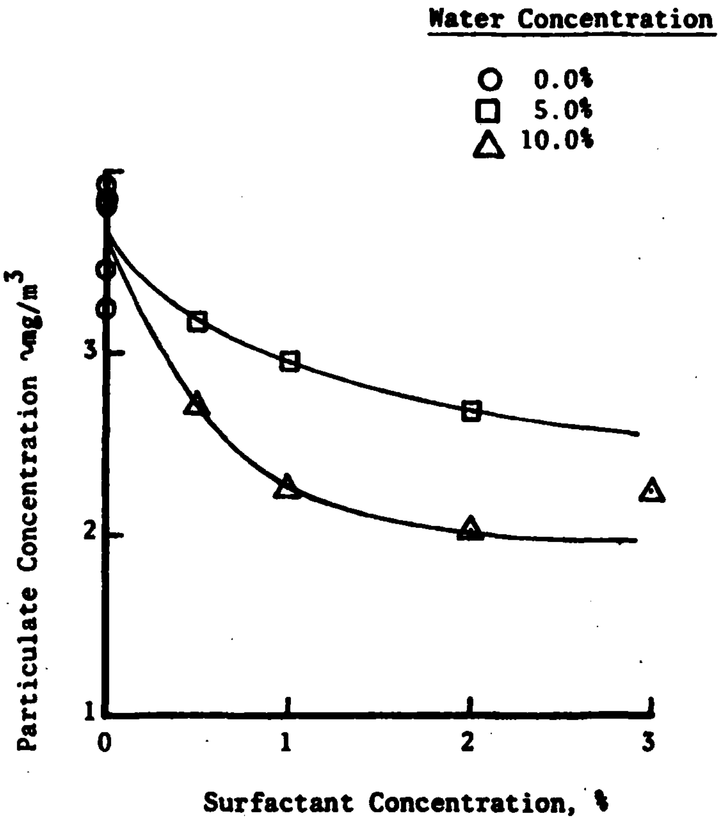


Figure 78 - Summary of Effects of Emulsion Characteristics on the Reduction of Exhaust Particulates, Program Phases 1-3

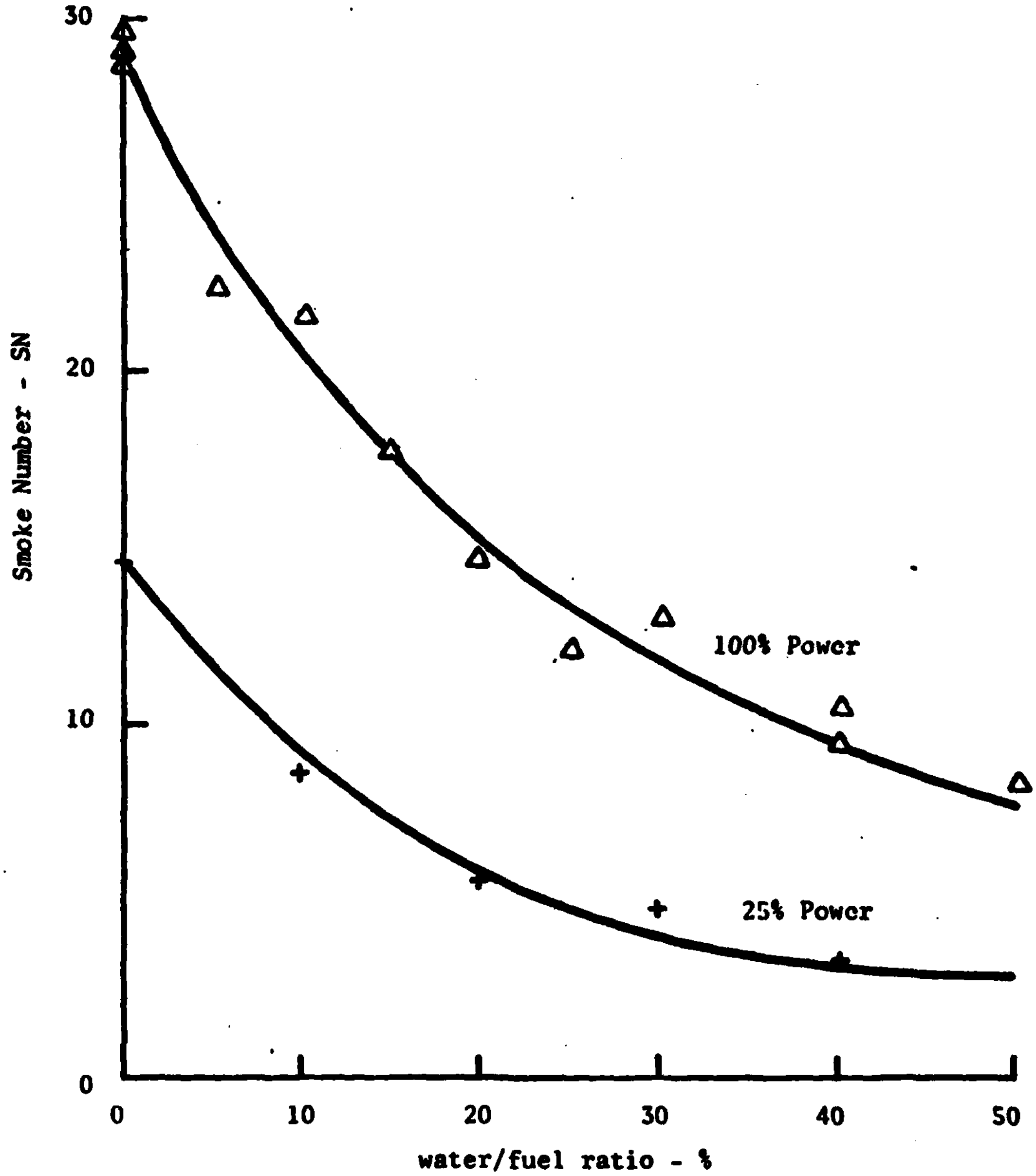


Figure 79 - Summary of Effects of Water Concentration on the Reduction of Smoke Number, Program Phases 4-7

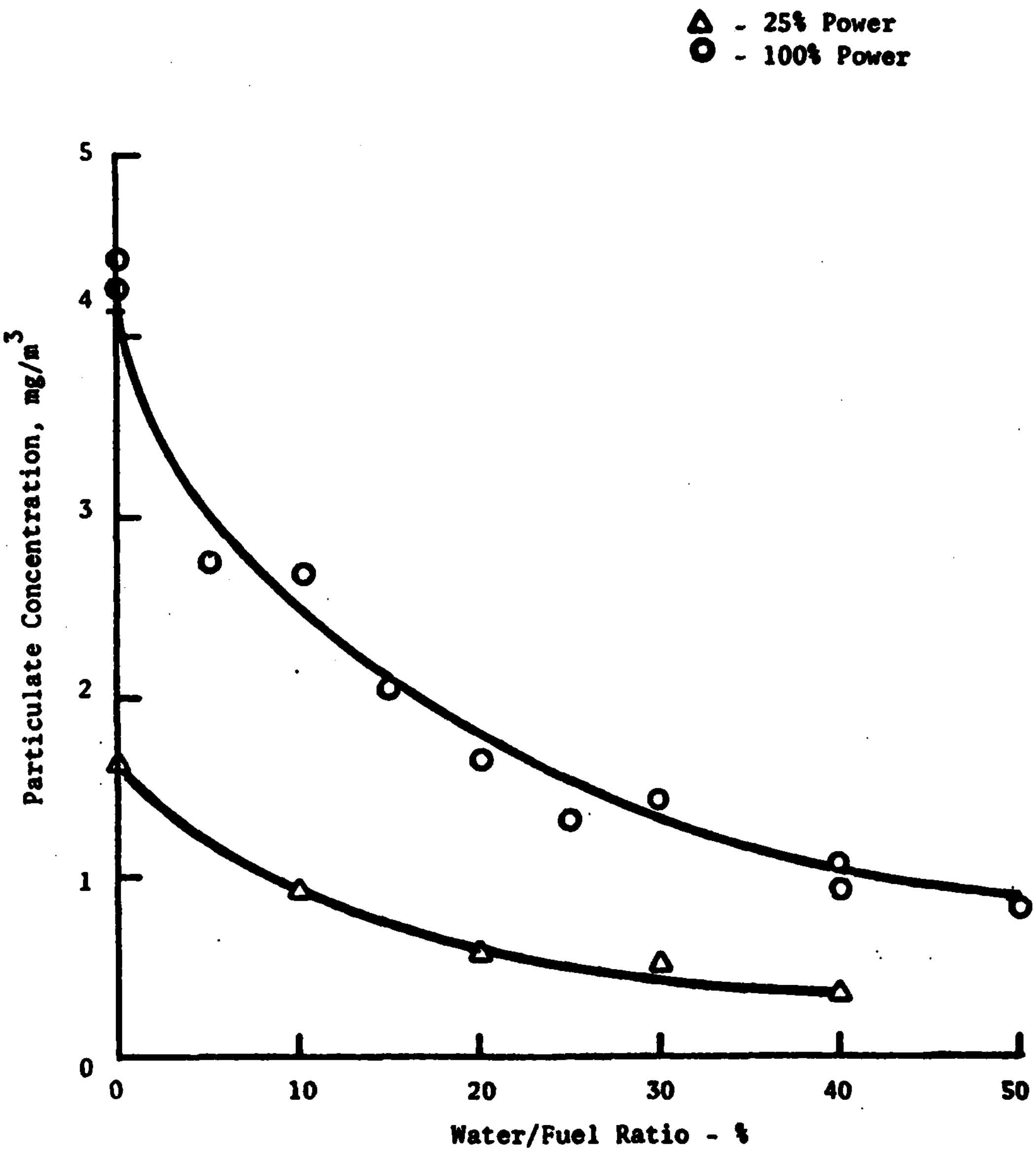


Figure 80 - Summary of Effects of Water Concentration on Particulate Concentration

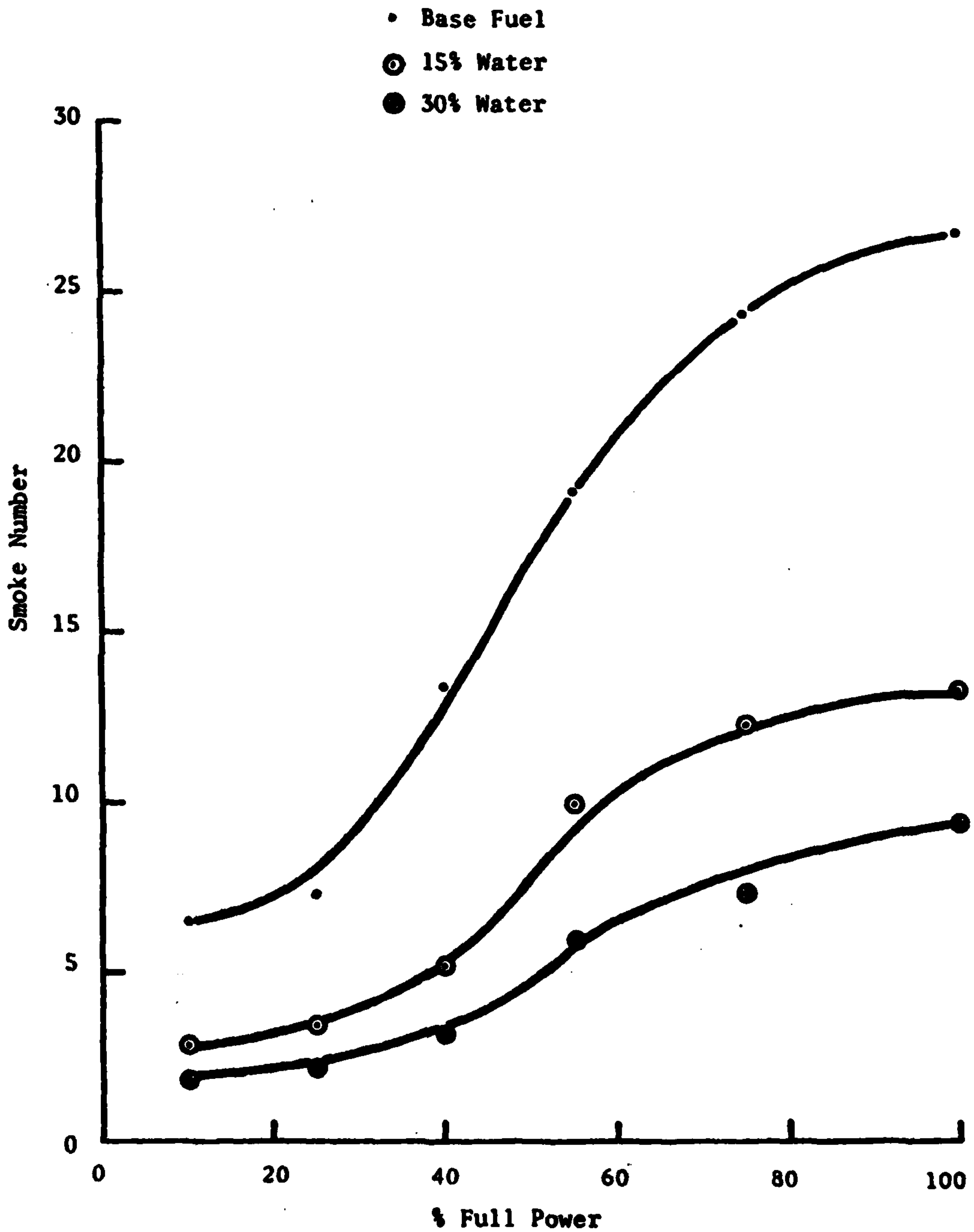


Figure 81 - Summary of Effects of Fuel/Water Emulsions on Smoke Number Throughout Engine Power Spectrum

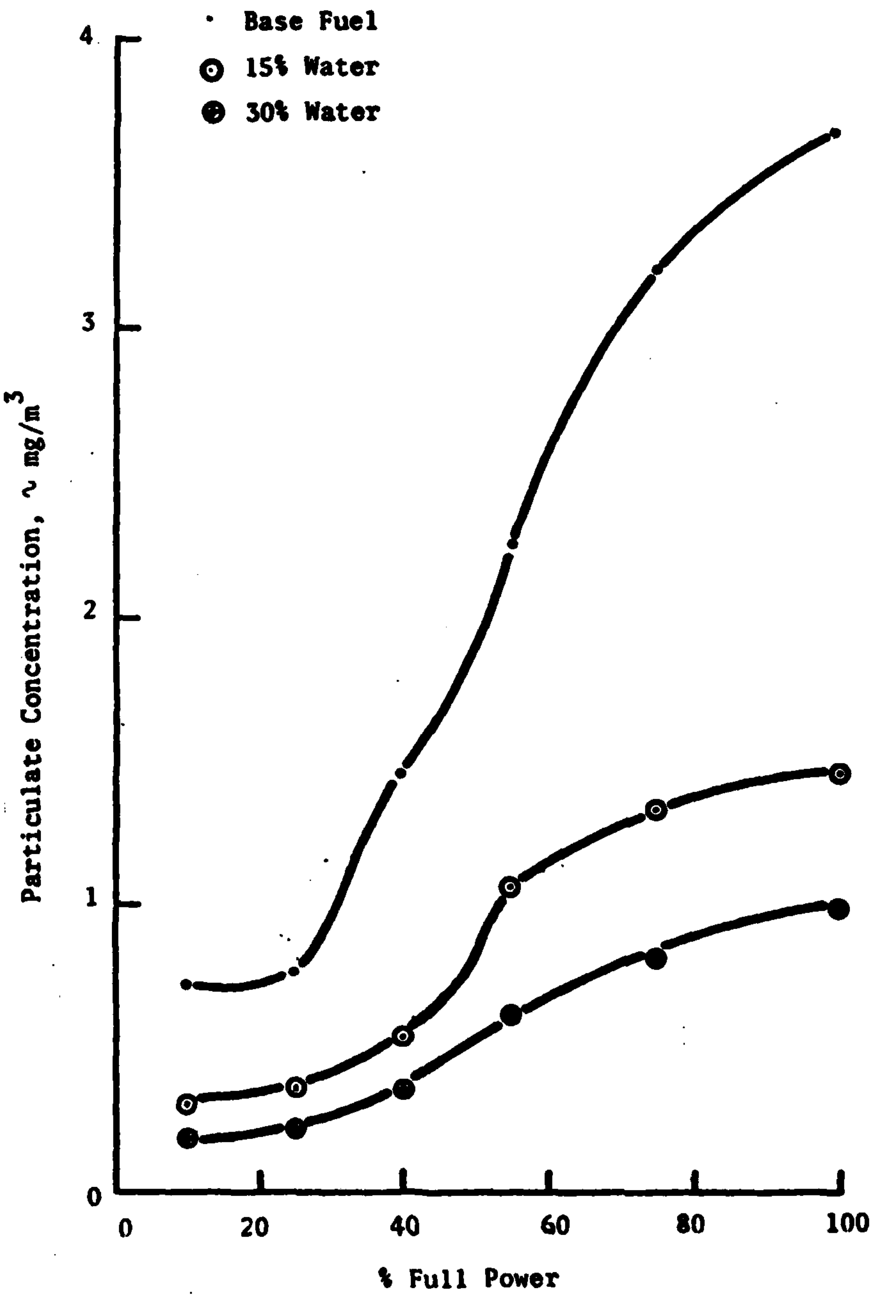


Figure 82 - Summary of Effects of Emulsion Characteristics on Particulate Concentration Over Engine Power Spectrum

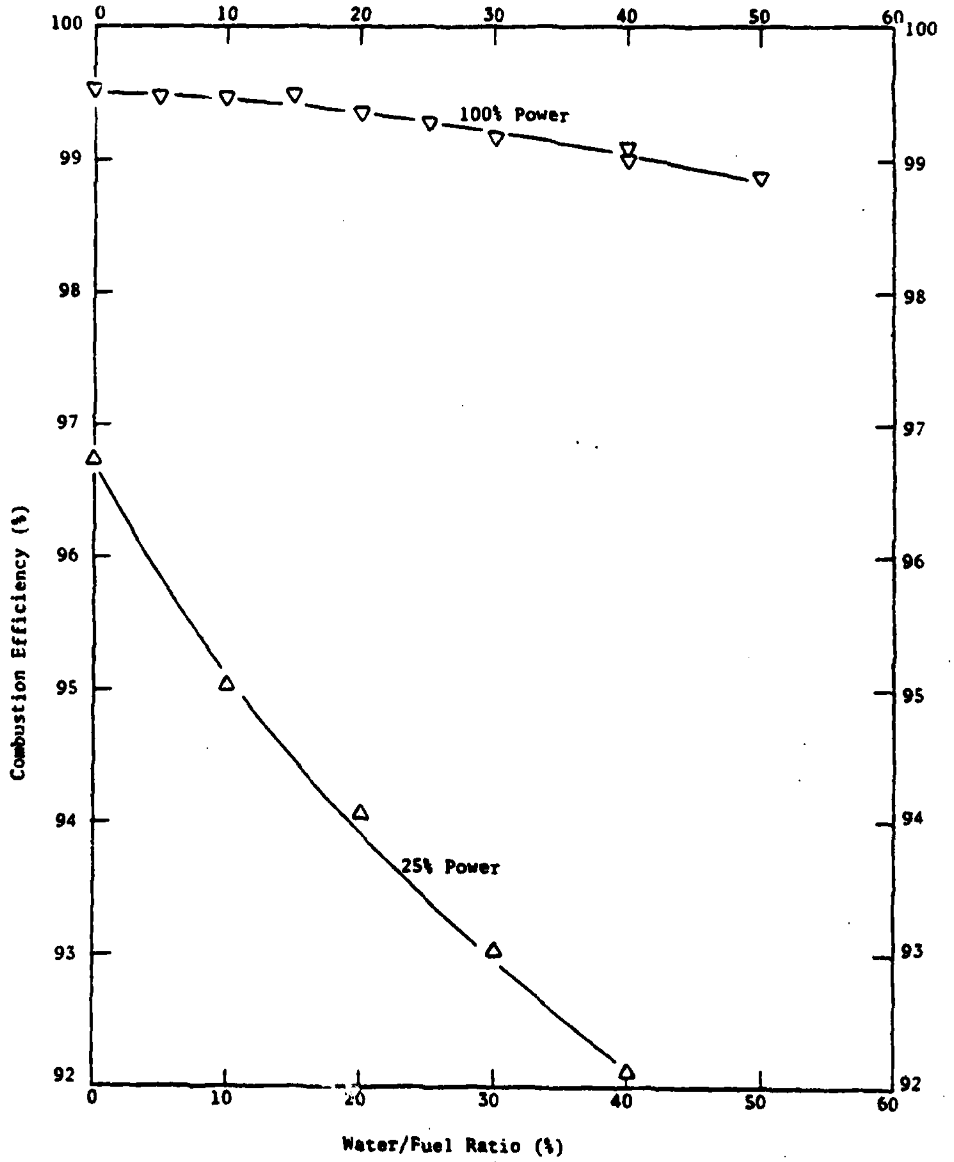


Figure 83 - Effect of Water Concentration on Combustion Efficiency

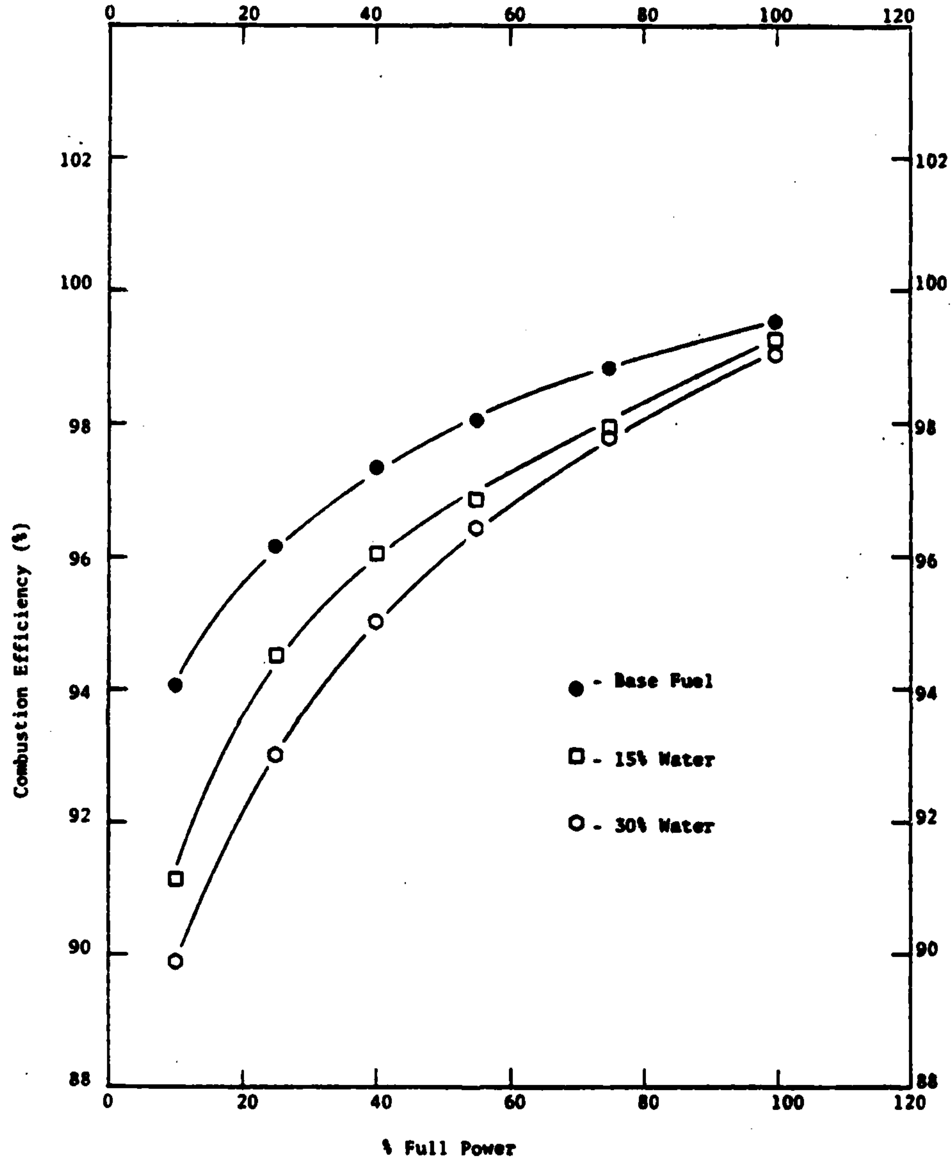


Figure 84 - Effect of Water Concentration on Combustion Efficiency Over the Engine Power Spectrum

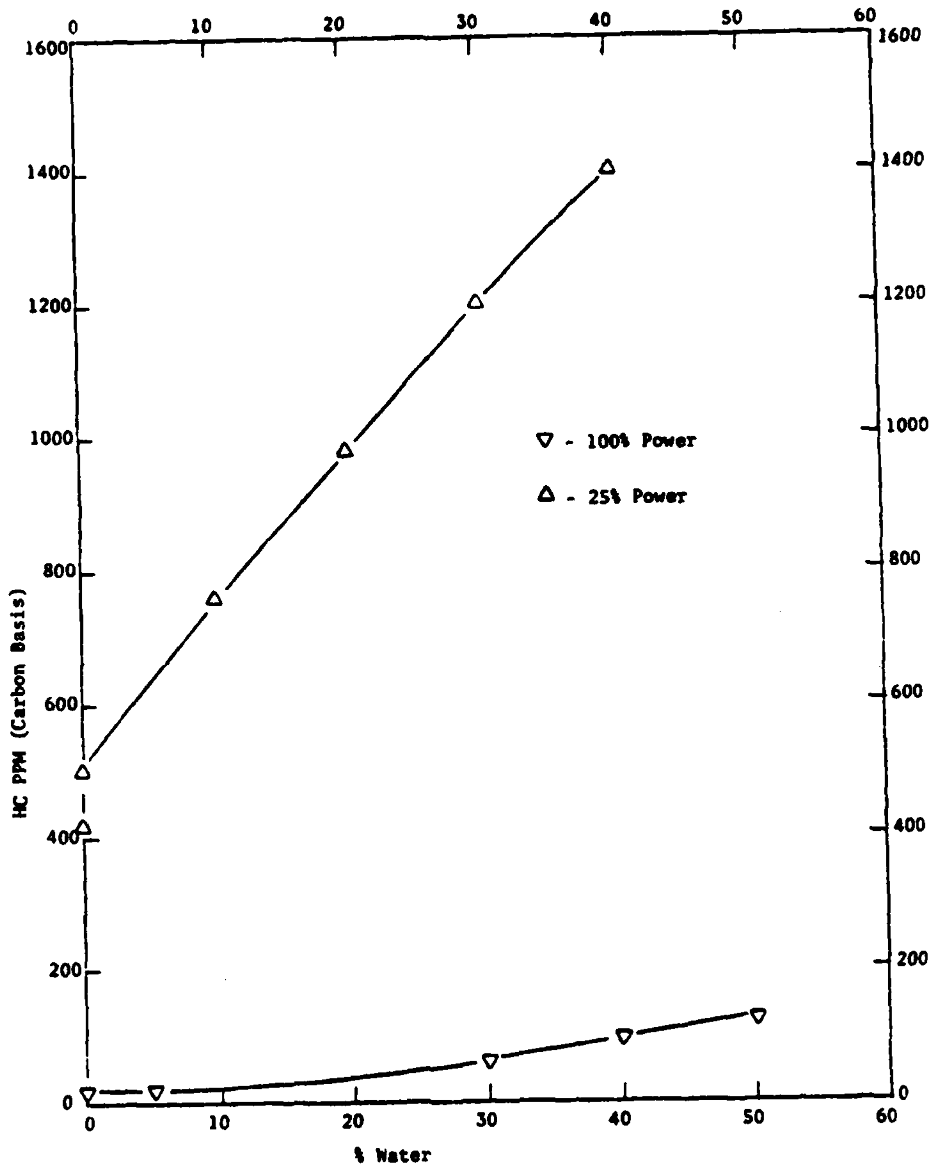


Figure 85 - Effect of Water Concentration on Hydrocarbon Emissions

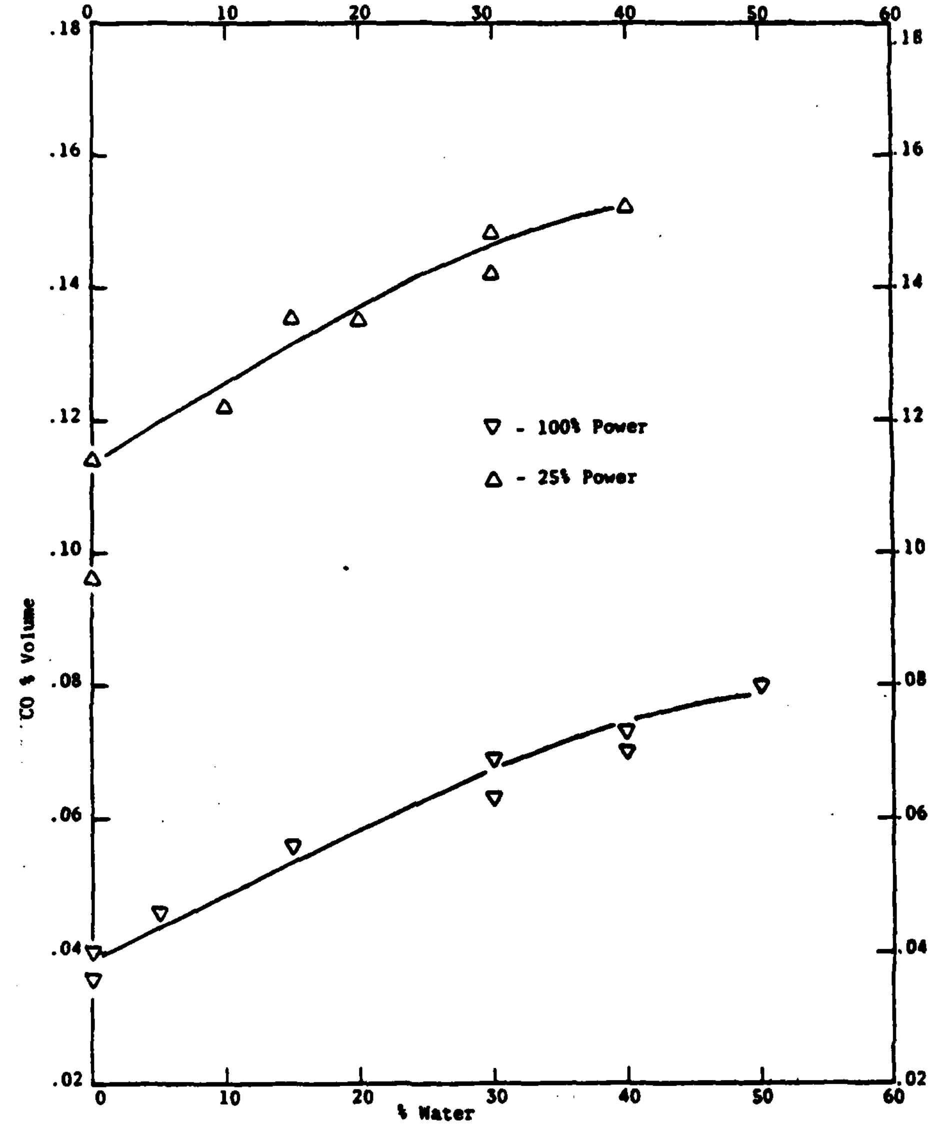


Figure 86 - Effect of Water Concentration on Carbon Monoxide Emissions

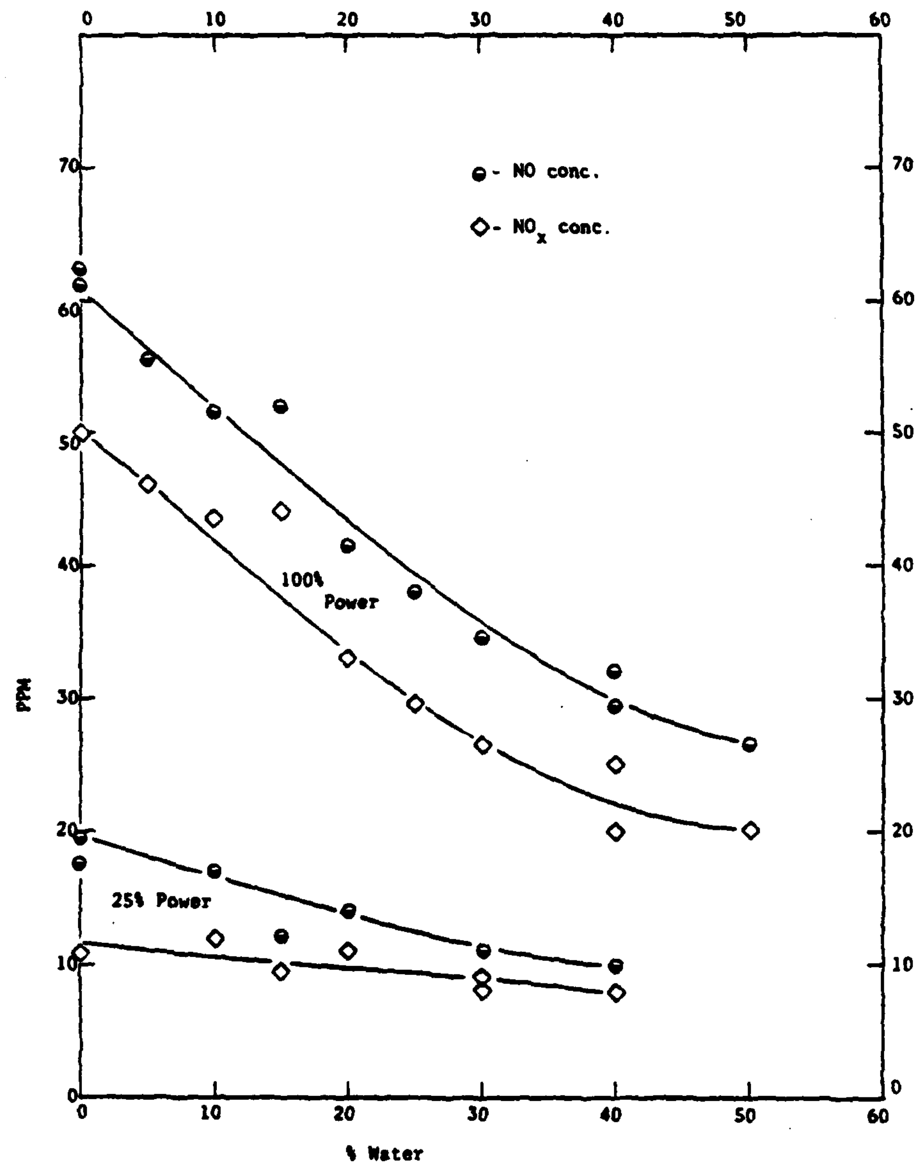


Figure 87 - Effect of Water Concentration on Oxides of Nitrogen Emissions

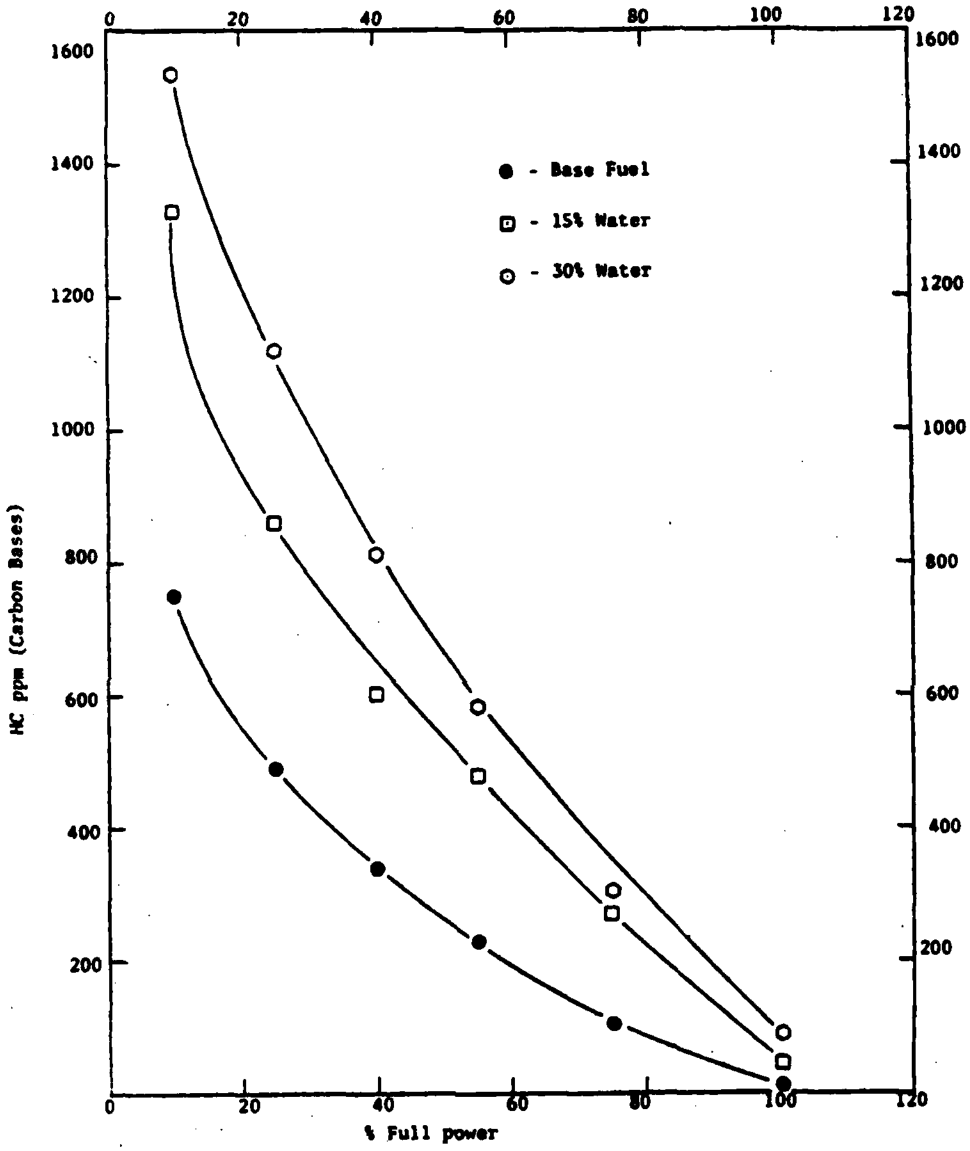


Figure 88 - Effect of Water Concentration on Hydrocarbon Emissions for Engine Power Spectrum

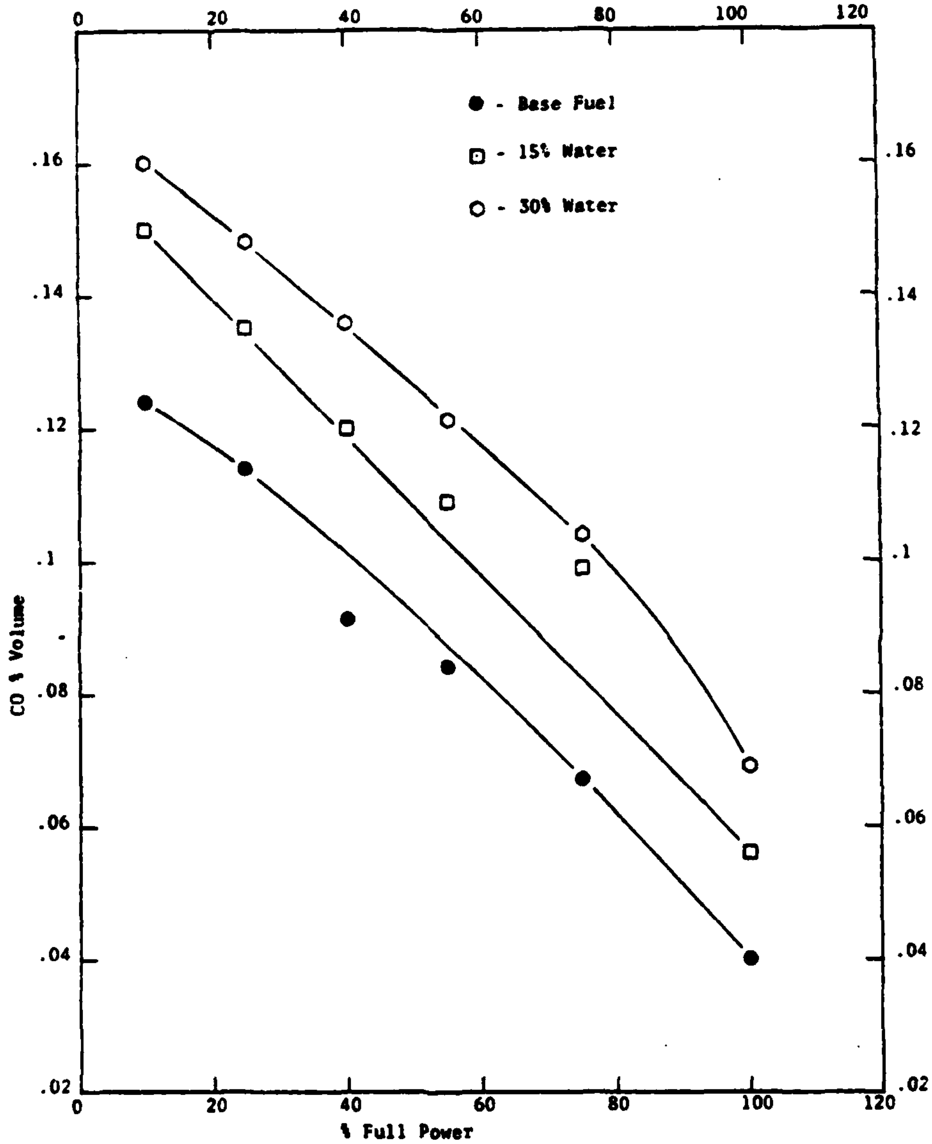


Figure 89 - Effect of Water Concentration on Carbon Monoxide Emissions for Engine Power Spectrum

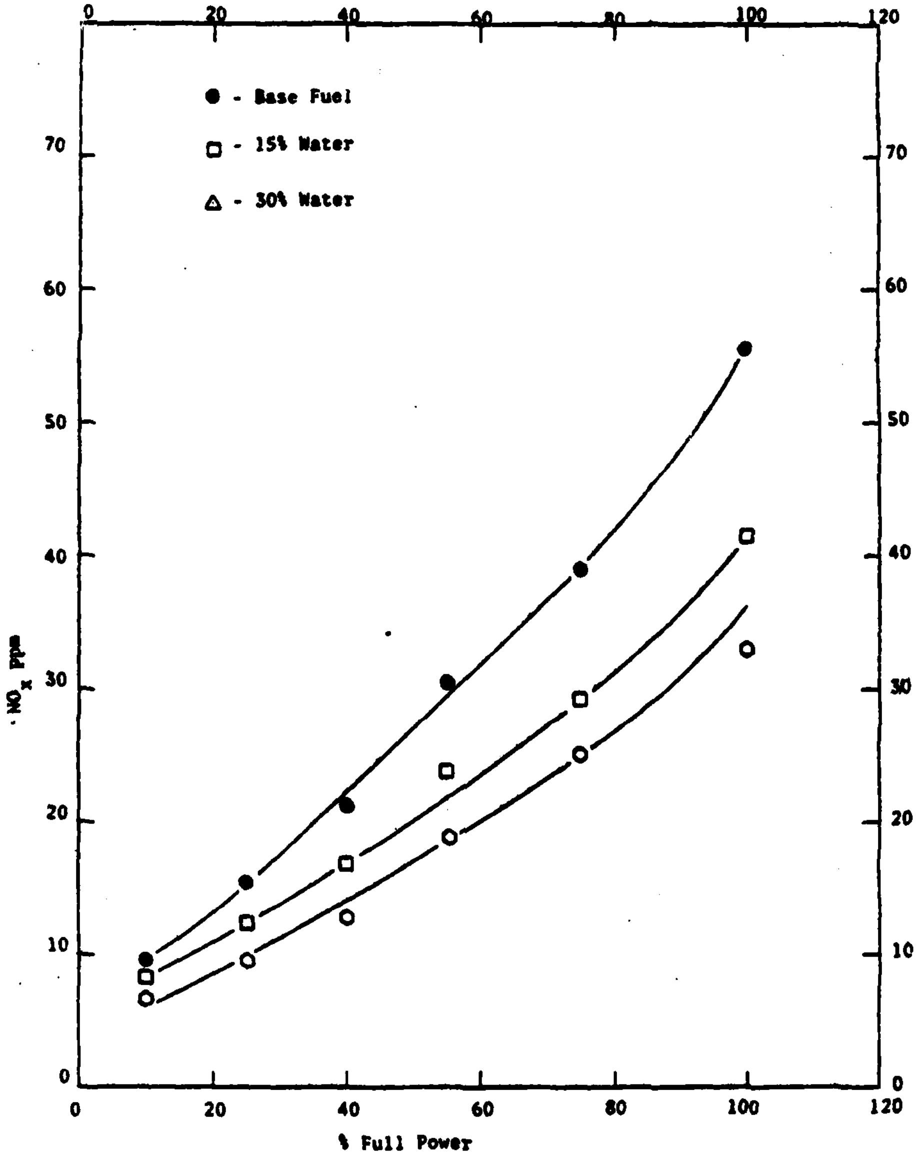
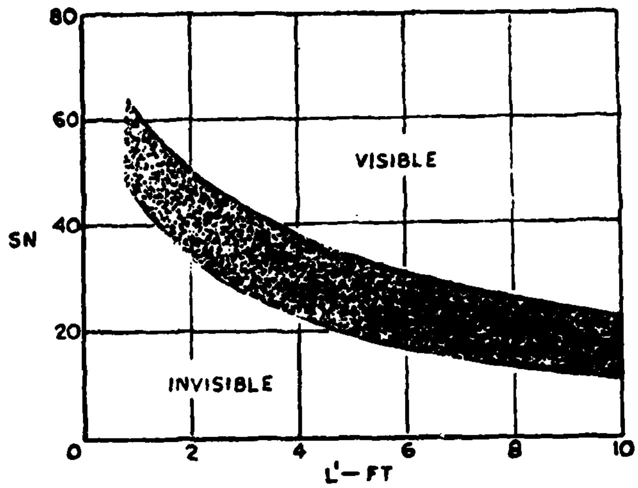
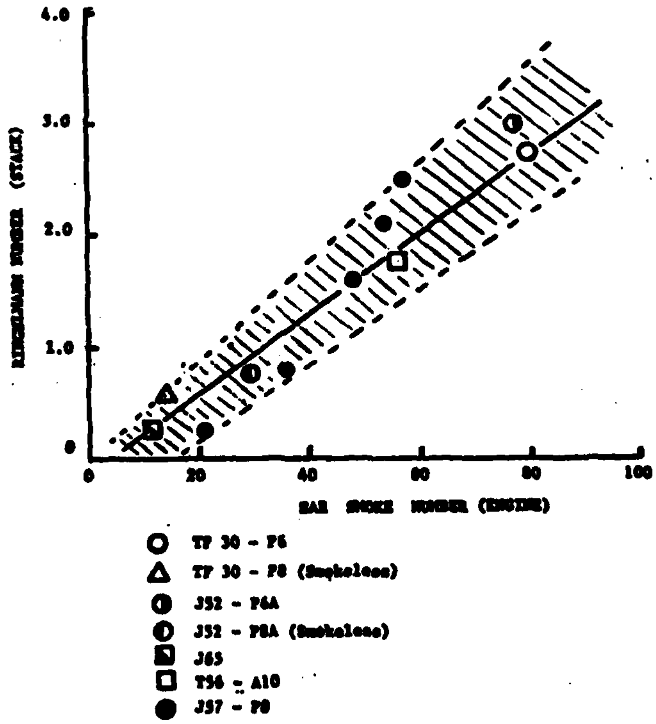


Figure 90 - Effect of Water Concentration on Oxides of Nitrogen Emissions for Engine Power Spectrum



(a)



(b)

Figure 91 - Correlations of Smoke Number to Plume Visibility According to (a) Champagne (1971), (b) Kelly (1973)

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